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a glossary of TERMS IN NUCLEAR SCIENCE and TECHNOLOGY

ASME 110-1957

NATIONAL RESEARCH COUNCIL
CONFERENCE ON GLOSSARY OF TERMS IN
NUCLEAR SCIENCE AND TECHNOLOGY

published by

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
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NATIONAL RESEARCH COUNCIL
CONFERENCE ON GLOSSARY OF TERMS IN NUCLEAR SCIENCE AND TECHNOLOGY

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A GLOSSARY OF TERMS IN NUCLEAR SCIENCE AND TECHNOLOGY

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FOREWORD

The need for a glossary of nuclear terms was widely recognized shortly after the close of the second world war. Workers in various fields of science and technology began independently to assemble the definitions of such terms. Generally the scope of the terms thus brought together was limited to the special field of interest of each assembling group. The overlapping interests of these groups and the desirability of having a single comprehensive glossary came to be appreciated through a series of spontaneous conversations. These conversations led to the organization of a Conference on a Glossary of Terms in Nuclear Science and Technology, under the auspices of the National Research Council (NRC). Meetings of this Conference were held in Washington on June 25, 1948, and January 13, 1950. Representatives from 17 technical societies, 10 government agencies and offices, and 6 divisions of the Council, as listed on the title page, were in attendance at one or both of these meetings. Early in the discussions, the progress already made by committees of The American Society of Mechanical Engineers (ASME) in developing a glossary of broad scope was clearly recognized.

After consideration of numerous details, the Glossary Conference at its second meeting authorized the carrying out of a plan drafted by the National Research Council. In brief, this plan was:

1) The NRC to coordinate activities in specialized fields with the program on which the ASME Nuclear Energy Glossary Committee had already made substantial progress.

2) The NRC to select qualified critics and Review Committees to make critical appraisals and revisions of the glossary terms and definitions as drafted by the ASME Glossary Committee.

3) The NRC to prepare manuscripts of glossary terms and definitions for publication in nine separate sections, each section to be a part of a "Preliminary Edition" of the Glossary.

4) In accord with a suggestion from the representative of the American Standards Association (ASA), the NRC to submit to the ASA a copy of each section of the preliminary edition of the Glossary as a "Proposed American Standard."

The ASME Nuclear Energy Glossary Committee prepared the glossary terms and definitions in nine sections as follows:

I Physics
II Reactor Theory
III Reactor Engineering
IV Chemistry
V Chemical Engineering
VI Biophysics and Radiobiology
VII Instrumentation
VIII Isotopes Separation
IX Metallurgy

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The complete membership of the ASME Nuclear Energy Glossary Committee, some of whom served for limited periods, was as follows:

John R. Dunning, ***Chairman***
Columbia University

Clement F. Burnap, ***Secretary to January 1, 1951***
Kellex Corporation

John F. Hogerton, ***Secretary after January 1, 1951***
Vitro Corporation of America

Karl Cohen
H. K. Ferguson Co.

George W. Dunlap
General Electric Co.

Morris Kolodney
College of the City of N. Y.

Edith H. Quimby
Columbia University

Henry Semat
College of the City of N. Y.

Hyman H. Goldsmith*
Brookhaven National Lab.

Thomas O. Jones
Argonne National Lab. and
Haverford College

Nicholas M. Smith, Jr.
Oak Ridge National Lab.

Arthur P. Weber
Kellex Corporation

Clinton J. T. Young
Kellex Corporation

Hoylande D. Young
Argonne National Lab.

*** Deceased**

The affiliation listed for each member is for the period of active Committee participation.

One or more members of this Committee was primarily responsible for selecting the terms and drafting the definitions thereof for one of the nine glossary sections. As shown below, that member was invited by NRC to serve as Chairman of the Review Committee for that section.

The processing procedure used in preparing each section of the Glossary was as follows:

1) A group of scientists (later referred to as Critics) was invited by NRC to examine and critically to comment upon the selection of terms and their definitions for a given section of the Glossary as submitted by the ASME Glossary Committee.

2) The comments from the Critics were assembled for each term in that section and turned over to a Review Committee, the Chairman of which had actively participated in preparing the ASME draft of terms and definitions for that section. Other members of the Review Committee were selected largely from the list of Critics for that section. Each Review Committee was given full responsibility for preparing the "Preliminary Edition" for its section. This assignment of distributed responsibility, of course, resulted in some lack of uniformity in the style and method of presenting the meaning of a term and in the structural features of the manuscripts for the various sections, but certain gains resulted from the freedom to use diversified forms of presentation.

In general, the aim was to limit the inclusion of terms in each section of the Glossary to the following categories: (1) peculiar to the field of nuclear energy; (2) used in this field in a different sense or with different emphasis from what is commonly understood in other connections; and

(3) used elsewhere in the same way, but so infrequently as to be unfamiliar. However, a liberal application of these criteria has been followed in order to provide useful and ready information for the reader in fields outside his own special interest.

A few items of information relating to the preparation of the several sections of the Glossary are recorded below under the following headings: Section number, title of section, number of participating Critics, date submitted for publication, and membership of Review Committee, with affiliation at that time.

I PHYSICS 48 April 1953

Henry Semat, Chairman
College of the City of N. Y.

Duane Roller
Hughes Aircraft Co.

Truman P. Kohman
Carnegie Institute of Technology

Arthur H. Snell
Oak Ridge National Lab.

II REACTOR THEORY 16 May 1952

Nicholas M. Smith, Jr., Chairman
Oak Ridge National Lab.

J. W. Butler
Argonne National Lab.

Gerald H. Goertzel
Nuclear Development Associates, Inc.

Eugene Greuling
Duke University

Henry Hurwitz
General Electric Co.

III REACTOR ENGINEERING 22 October 1950

Clinton J. T. Young, Chairman
Kellex Corporation

Harvey Brooks
General Electric Co.

Clark Goodman
Massachusetts Institute of Technology

H. Etherington
Argonne National Lab.

A. Kalitinsky
Fairchild Engine and Airplane Corp.

George Weil
Atomic Energy Commission

IV CHEMISTRY 38 August 1951

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Argonne National Lab. and
Haverford College

Hoylande D. Young, Co-Chairman
Argonne National Lab.

Charles D. Coryell
Massachusetts Institute of
Technology

Gerhart Friedlander
Brookhaven National Lab.

Henri A. Levy
Oak Ridge National Lab.

V CHEMICAL ENGINEERING 10 January 1950

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Thomas B. Drew
Columbia University

James N. Addoms
Massachusetts Institute of
Technology

Miles C. Leverett
Fairchild Engine and Airplane Corp.

VI BIOPHYSICS AND RADIOBIOLOGY 42 January 1950

Edith H. Quimby, Chairman
Columbia University

Howard L. Andrews
National Institutes of Health

Alexander Hollaender
Oak Ridge National Lab.

Sterling B. Hendricks
U. S. Department of Agriculture

Lauriston S. Taylor
National Bureau of Standards

VII INSTRUMENTATION 43 February 1951

G. Wesley Dunlap, Chairman
General Electric Co.

George C. Baldwin
General Electric Co.

J. B. H. Kuper
Brookhaven National Lab.

Dean B. Cowie
Carnegie Institution of Washington

William Elmore
Swarthmore College

VIII ISOTOPES SEPARATION 14 August 1951

Karl Cohen, Chairman
H. K. Ferguson Co.

C. P. Keim
Oak Ridge National Lab.

W. H. Furry
Harvard University

D. J. Pflaum
Atomic Energy Commission

IX METALLURGY 22 April 1951

Morris Kolodney, Chairman
College of the City of N. Y.

Lawrence K. Jetter
Oak Ridge National Lab.

John H. Hollomon
General Electric Co.

Bruce A. Rogers
Iowa State College

The preparation of the Glossary sections was greatly assisted by the joint program of the Office of Naval Research and the Atomic Energy Commission. Our thanks are hereby extended to the Critics for their helpful assistance. To the members of the Review Committee for each section of the Glossary we are especially indebted. They gave freely and extensively of their time and attention to the preparation of their respective sections for which the Council wishes hereby to extend and record its most cordial thanks.

Following the publication of the separate sections of the Glossary, a consolidated copy of the entire Glossary was assembled in a single alphabetical order by the ASME staff and distributed as an interim edition, pending the preparation of this edition.

PREFACE

In each section of the "Preliminary Edition" of the Glossary the readers were invited to send suggestions and criticisms to the Chairman of the NRC Glossary Conference for consideration in making a further review of the terms and definitions for publication in a combined edition of all the terms arranged in a single alphabetical list. Such comments and criticism together with similar advice obtained in other ways have been utilized in preparing copy for the present consolidated edition. This is not a revised edition in the usual sense, as an effort has not been made systematically to include new terms that have come into use with the growth of the science or to add terms that heretofore were in a classified status. However, considerable effort has been made to eliminate errors, to recast questioned phraseologies, to improve the clarity of statements and to adjust the presentation to a uniform format. In making these changes we have had generous assistance from numerous persons to whom our thanks and appreciation are hereby acknowledged. Special recognition goes to the Chairmen and other members of several of the section Review Committees.

For the preparation of this consolidated edition of the Glossary much credit is due Mrs. Helen S. Stearns. Her grasp of the objective to be sought in the overall planning of its structure and her ability and readiness to take full responsibility for working out the details have greatly facilitated the undertaking. For this type of assistance and cooperation I am personally deeply grateful.

R. C. Gibbs, Chairman
NRC Conference on Glossary
of Terms in Nuclear Science
and Technology

A

"A" neutrons
Neutrons of such energy that they are strongly absorbable by silver. Usage is obsolete.

aberration, chromosome
(See chromosome aberration)

absorber

1. A substance that effects absorption.
2. A sheet or other body of material placed between a source of radiation and a detector for purposes such as: (a) determining the nature or the energy of the radiation; (b) reducing the intensity of the radiation at the detector, as in shielding; or (c) giving the radiation some desired characteristic, as by preferential transmission of one component of the radiation. Such an absorber may function through a combination of processes of true absorption, scattering, and slowing-down.
3. (Nuclear reactor) A substance that absorbs neutrons without reproducing them. Such a substance may be useful in control of a reactor *(see absorption control)* or, if unavoidably present, may produce an undesired impairment in neutron economy. Neutron absorption is an important function of the shield surrounding a reactor. Almost all substances absorb slow or thermal neutrons to some extent, cadmium and boron being especially effective. For absorbing gamma rays, dense materials are most effective.

absorption

1. The process whereby the total number of particles or quanta emerging from a body of matter is reduced relative to the number entering, as a result of interaction of the particles with the body.
2. The process whereby the kinetic energy of a particle is reduced while traversing a body of matter. This loss of kinetic energy of corpuscular radiation is also referred to as moderation, slowing, or *stopping*.
3. The process whereby some or all of the energy of electromagnetic radiation is transferred to the substance on which it is incident or which it traverses.
4. For particulate radiation, energy is lost by collisions with electrons or nuclei. For photons, the reduction is due to the transfer of the energy to electrons by scattering and photoelectric processes, and, at voltages greater than a million, by pair production.

Note: In the above sense this term is used interchangeably with attenuation. More specifically absorption refers to processes by which the radiation disappears or is transformed and not merely scattered.

5. (Chemical engineering) The transfer of a gas into a liquid in which it is soluble.

absorption, photoelectric
(See photoelectric absorption)

absorption coefficient, μ
A measure of the rate of decrease in intensity of a beam of photons or

particles in its passage through a particular substance. The **linear absorption coefficient** μ_l is the fractional decrease in intensity per unit distance traversed, or $\mu_l = -dI/Idx$, where I is the intensity of the beam and x is the distance traversed. If μ_l is independent of x, then $I = I_o e^{-\mu_l x}$, where I_o is the initial intensity of the beam. The **mass absorption coefficient** μ_m is the fractional decrease in intensity per unit surface density. For a substance of density ρ, μ_m is equal to μ_l/ρ, and hence is independent of the density.

The **atomic absorption coefficient** μ_a of an element is the fractional decrease in intensity, per number of atoms per unit area; it is equal to the linear absorption coefficient divided by the number of atoms per unit volume, or to the mass absorption coefficient divided by the number of atoms per unit mass. If the medium consists of only one nuclide, the atomic absorption coefficient μ_a is equivalent to the *total cross section* for the radiation in question.

(Chemical engineering)

1. The amount of gas at given conditions of temperature and pressure which saturates a unit quantity of liquid solvent.
2. A mass transfer coefficient for gas absorption.

absorption coefficient, linear (radiobiology)

A factor expressing the fraction of a beam of radiation absorbed in unit thickness of material. In the expression $I_d = I_o e^{-\mu d}$, I_o is the initial intensity, I_d the intensity after passage through a thickness d of the material, μ is the linear absorption coefficient. If d is expressed in mm, μ is per mm; if d is in cm, μ is per cm.

absorption coefficient, mass

The linear absorption coefficient per cm divided by the density of the absorber in grams per cc. It is frequently expressed as μ/ρ, where μ is the linear absorption coefficient and ρ the density.

absorption control

Control of the reaction in a nuclear reactor by use of a neutron absorber to remove part of the neutrons. Adjustment is made by varying the effective amount of absorber in or near the core. The most common arrangement is to incorporate the absorber in rods that can be moved in or out to a position where they have the desired effect. Useful absorbers for this purpose are cadmium and boron (the latter commonly in the form of boron steel). Since it is necessary to be able to raise as well as lower the neutron flux, the reactivity of the reactor with absorbers withdrawn must be somewhat higher than would be required for the reactor to be just critical. Therefore, at constant reaction rate, there is some consumption of neutrons in the control rods of an absorption-controlled reactor. Fertile material sometimes is used as control absorber to make this consumption useful and to improve over-all neutron economy. *(See control rod; neutron economy)*

absorption curve

A graph in which the intensity of the transmitted radiation is plotted as a function of thickness of the material traversed.

Usually the logarithm of the transmitted intensity is plotted vs. the surface-density of absorber measured, for example, in g/cm^2. Most frequently the curve is determined for the purpose of characterizing the incident radiation as to its nature and energy.

(Chemistry) The absorption curves generally used by chemists are attenuation curves because no differentiation between scattering and absorption processes is usually made. The form of the curve is somewhat dependent on the experimental arrangement. (Radiobiology):

1. Curve showing variation in dosage rate with thickness of absorber. More properly called **transmission curve.**
2. Ultraviolet and longer wavelengths: Curve showing variations in absorption as a function of wavelength.

absorption discontinuity, edge, or limit
A discontinuity in the *absorption coefficient* of a substance for a particular type of radiation when expressed as a function of the energy (or frequency or wavelength) of this radiation. For example, the absorption coefficient of an element for x-rays shows discontinuities at definite wavelengths which are designated as the **K absorption limit,** the **L_I, L_{II}, L_{III} absorption limits,** and so forth.

abundance
(See cosmic abundance; relative abundance of an isotope)

abundance ratio
The ratio of the number of atoms of various isotopes in any mixture; it expresses the relative abundance of the various species.

accelerating chamber
Any evacuated envelope in which charged particles are accelerated.

accelerating tube
An accelerating chamber of general tubular construction, either toroidal as in a betatron or cylindrical with a large length to diameter ratio as in an electrostatic accelerator or linear electron accelerator. It may be sealed off or continuously evacuated.

accelerator
A device for imparting large kinetic energy to charged particles, such as electrons, protons, deuterons, and helium ions. Common types of accelerators are the cyclotron, synchrotron, synchro-cyclotron, betatron, linear accelerator, and Van de Graaff electrostatic accelerator. *(See Van de Graaff generator)*

accidental coincidence
(See coincidence)

accidental coincidence correction
The correction made in coincidence counting to take into account the chance occurrence of unrelated signals within the resolving time of the apparatus.

actinides
A name proposed for the series of elements of atomic numbers 90-101 inclusive. The series would presumably include the undiscovered elements of atomic numbers 102 and 103. The term "actinide" is proposed by analogy to "lanthanide." Justification for the proposal is based on the increasing stabilization of the tripositive oxidation state with increasing atomic number, evidence for the progressive filling of the 5f shell, especially for the elements 92 to 96, and the actinium-like behavior of curium, the seventh member of the series. The names "thoride" and "uranide" also have been suggested for some of the elements of this series.

A name proposed for elements of the last row of the periodic system in oxidation state +3. The compounds of the elements beyond actinium in this state are generally isostructural with the corresponding ones of actinium and of the lanthanides. Compare similar usage for *thorides*, *protactinides*, and *uranides*.

actinium (Ac)
An element, atomic number 89, discovered in 1899 by Debierne. Two naturally occurring isotopes are known: Ac^{227}, a descendant of U^{235}, has a half-life of 21.7*y* and Ac^{228} ($MsTh_2$) has a half-life of 6.13*h*. An important synthetic source of the element is the nuclear reaction

$$Ra^{226}(n,\gamma)\ Ra^{227} \xrightarrow{\beta^-} Ac^{227}$$

The only known oxidation state is +3.

actinium A (AcA)
The common name for $1.83 \times 10^{-3}s$ Po^{215}, a member of the actinium series.

actinium B (AcB)
The common name for 36.1*m* Pb^{211}, a member of the actinium series.

actinium C (AcC)
The common name for 2.16*m* Bi^{211}, a member of the actinium series.

actinium C′ (AcC′)
The common name for 0.52*s* Po^{211}, a member of the actinium series.

actinium C″ (AcC″)
The common name for 4.76*m* Tl^{207}, a member of the actinium series.

actinium D (AcD)
The common name for Pb^{207}, the stable end product of the actinium series. Natural lead contains 21.11% of this isotope.

actinium K (AcK)
The common name for 21*m* Fr^{223}, a member of the actinium series.

actinium X (AcX)
The common name for 11.2*d* Ra^{223}, a member of the actinium series.

actinium series
The series of nuclides resulting from the decay of U^{235}. Mass numbers of all members are given by $4n + 3$, where n is an integer The sequence is also known as $4n + 3$ series or actinouranium series. Many synthetic nuclides decay in collateral series into this sequence. The sequence of decay in the actinium series as it occurs in nature is as indicated in fig. 1. (*See radioactivity, natural*)

actinon (An)
The common name for 3.92*s* Em^{219}, a member of the actinium series. *(See emanation)*

actinouranium (AcU)
A common name for $7.13 \times 10^{8}y$ U^{235}, the natural parent of the actinium series. (*See uranium-235*)

actinouranium series
(See actinium series)

activated water
The passage of ionizing radiation through water produces, temporarily, ions, atoms, radicals, or molecules in a chemically reactive state. The combined effect of all such entities is said to be due to activated water. Their identity has not been established with certainty, although evidence exists of the presence of free hydroxyl radicals and hydrogen atoms.

activation
The process of inducing radioactivity through neutron bombardment or by other types of irradiation. (*See cross section, activation*)

activation analysis
A method of chemical analysis, especially for small traces of material, based on the detection of characteristic radionuclides following a nuclear bombardment.

active
1. Fissionable (active material).
2. Radioactive (active sample).
3. The active part of a reactor is the core (active lattice).

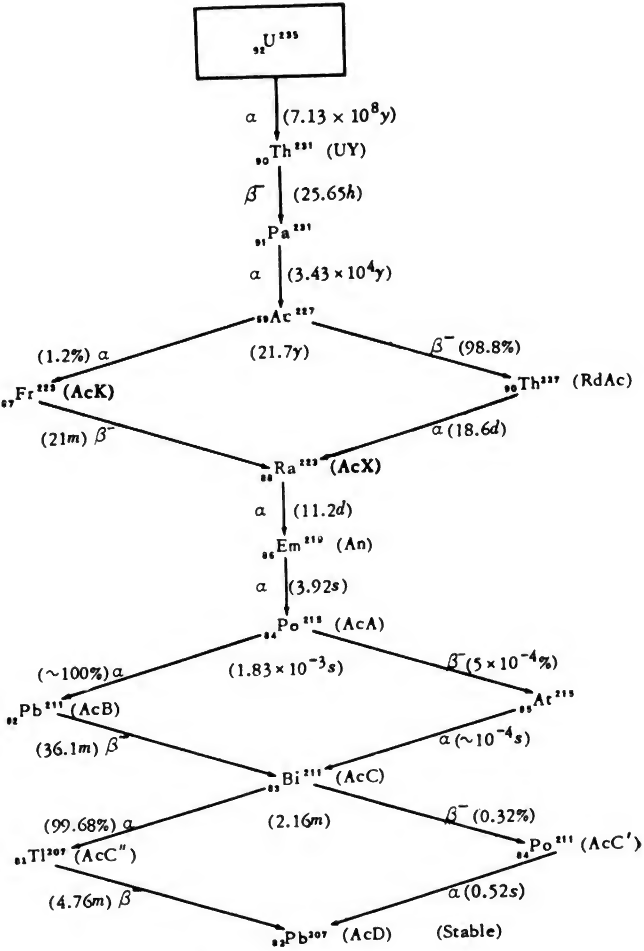

Fig. 1 The actinium series.

active deposit

1. The radioactive decay products deposited on a surface exposed to radon, actinon or thoron gas.
2. By extension, any radioactive decay products deposited on a surface exposed to a radioactive gas.
3. Any radioactive material deposited on a surface.

active lattice
The core of a lattice reactor, in which fissionable and nonfissionable materials are arranged in a regular pattern. *(See lattice)*

active product
A radioactive *decay product* of a radionuclide. *(See daughter)*

active section
The part of a nuclear reactor in which the reproduction factor, aside from leakage, is unity or greater so that the chain reaction is potentially self-sustaining.

activity

1. The number of atoms decaying per unit of time. The unit of activity is the curie, 3.7×10^{10} disintegrations per second.
2. A measure of the intensity of emission from a radioactive substance in terms of observable effects, often expressed in counts per unit of time.
3. A term frequently used to designate a particular radioactive nuclide.
4. A term frequently used to designate a particular radiation component, e.g., the gamma activity of a source.
5. A term commonly used for *radioactivity.*
6. In practice, activity is often expressed in terms of observable effects, such as counts per minute or roentgens per hour at one meter.

activity curve
A curve, usually derived from experimental data, showing the *activity* of a radioactive source as a function of time. (*See activity; decay curve; growth curve*)

acute exposure
(See exposure, acute)

adjoint function
A mathematical concept which, in reactor theory, includes the *importance function* as a special case.

adsorbate
A substance which is adsorbed. *(See adsorption)*

adsorbent
A solid on which a substance is adsorbed. *(See adsorption)*

adsorption
The concentration of the molecules of a fluid or one of its constituents at a phase boundary. Such constituents need not be in true solution.

advantage factor (nuclear reactor)
The ratio a/b where a is the radiation dosage received in a particular time interval at a position where an enhanced effect may be produced and b is the radiation dosage received by a sample in the same time interval at some reference position in a nuclear reactor.

after-heat
Heat resulting from residual activity after a reactor has been shut down.

age (geology)
The interval of time between some geologic event, such as the formation of a mineral, and the present time. For many geologic events it is possible to determine only the **stratigraphic age**, which is the relative age based on the position of a speci-

men in the sequence of geologic strata. **Absolute ages** of a number of minerals have been determined by means of natural radioactivity; and from the known positions of these minerals in the stratigraphic sequence, the latter can be converted into an absolute time scale. If the age is calculated from the relative numbers of atoms of a stable radiogenic end product and radioactive parent present, the method is designated by the name of the end product. Examples are the **lead age** and **helium age** of a uranium-containing and/or thorium-containing mineral, the **strontium age** of a rubidium-containing mineral, and the **argon age** and **calcium age** of a potassium-containing mineral. For a uranium-containing mineral, the **chemical age** is that calculated from chemical analyses only, assuming that all of the lead present is radiogenic. Isotopic analysis of the lead permits correction for nonradiogenic lead and the calculations of the independent **Pb^{206}** (or **RaG**) **age, Pb^{207}** (or **AcII**) **age** and **Pb^{208}** (or **ThD**) **age.** The **Pb^{207}/Pb^{206}** (or **AcD/RaG**) **age** is not independent, but provides a check and, moreover, can be calculated in the absence of chemical analyses. If the age is calculated from the proportion of a relatively short-lived radionuclide present, the name of the latter designates the method; thus the **radium age** (or the **ionium age**) is calculated from the numbers of radium (or ionium) atoms present originally, now, and when equilibrium is established with ionium (or uranium). The **radiocarbon age** is calculated from the specific activity, due to C^{14}, of the carbon in a once-living object; such **radiocarbon dating** is possible because C^{14} is produced in the atmosphere by cosmic rays and is incorporated into all living objects; after death the C^{14} activity decays exponentially with a half-life of 5568 yr.

age, τ (reactor theory)

The value calculated for the slowing-down area used by Fermi age theory. It is defined by

$$\tau(E, E_o) = \int_{E}^{E_o} \frac{D(E')}{\xi \sigma_s(E')} \frac{dE'}{E'}$$

where E' is the neutron energy
D is the diffusion coefficient of neutron flux
ξ is the logarithmic energy decrement
σ_s is the scattering cross section per unit volume.

The term is often synonymous with *slowing-down area.*

age equation

$$\nabla^2 q - \frac{\partial q}{\partial \tau} = 0$$

where q is the slowing-down density. *(See Fermi-age model)*

age hardening (precipitation hardening)

A process of hardening an alloy by aging at room temperature or elevated temperatures which occurs only in alloys which are supersaturated solid solutions. The aging process, which increases hardness and strength while usually decreasing ductility, is associated with the precipitation of one or more phases which may or may not produce recognizable particles.

aggregate recoil

The ejection, from the surface of a sample, of a cluster of atoms attached to one that is recoiling as the result of alpha-particle emission. Although the phenomenon may be quite common, the amount of matter thus carried away is so small as to be undetectable unless it is strongly radioactive. It is observed with strong preparations of alpha-active materials of high specific activity, such as nearly pure polonium compounds, as a migration of a small fraction of the radioactivity onto clean surfaces in the vicinity.

agranulocytosis (biology)
Complete or nearly complete absence of granulocytes from blood.

air dose (x-rays)
(See dose, air)

air equivalent
(See stopping power)

air equivalent ionization chamber
(See ionization chamber, air-wall)

air monitor
Any device for detecting and measuring airborne radioactivity for warning and control purposes.

air-wall ionization chamber
(See ionization chamber, air-wall)

albedo (neutron)
The reflection factor of a surface for neutrons. For example, if *N* neutrons pass through air and strike a slab of paraffin, with the result that, at the end of the process (in which repeated scatterings and traversals of the boundary surface are possible), *n* neutrons are in the air and *N-n* neutrons are in the paraffin, then *n/N* is the albedo. In the case of steady flow, the albedo for traversal of a boundary from medium *A* into medium *B* is given by the ratio: (number from *B* into *A*)/(number from *A* into *B*). The term is borrowed from astronomy, where it refers to the reflection factor of a diffusively reflecting surface. The albedo of a region is the probability that a neutron entering into the region through a surface will return through the same surface.

allobar
A form of element having a different atomic weight from the naturally occurring form; hence, a form of element differing in isotopic composition from the naturally occurring form.

allowed transition
A transition between two states of a quantum mechanical system; this transition belongs to a class of transitions that has a high probability of occurring. For example, transitions in which the total angular momentum quantum number changes by one in units of *h*, are frequently allowed; and, other things being equal, a transition involving a change of one will take place with greater probability than a competing transition involving a change in this quantum number of two or more. *(See selection rules; forbidden transition)*

alpha (reactor theory)
1. The reciprocal of the asymptotic period.
2. The ratio, in a fissionable element, of radiative capture to fission cross section.

alpha chamber (instrumentation)
A counter tube or counting chamber for the detection of alpha particles; often operated in the non-multiplying (ionization chamber) or proportional region with pulse height selection to discriminate against pulses due to beta or gamma rays and to pass only those due to alpha particles.

alpha counter (instrumentation)
A system for counting alpha particles including an alpha counter tube, amplifier, pulse height discriminator, scaler and recorder, or the alpha counter tube plus the necessary auxiliary circuits for counting alpha particles. Often loosely applied to the alpha counter tube or chamber alone.

alpha counter tube (instrumentation)
A counter tube or counting chamber for the detection of alpha particles. *(See alpha chamber)*

alpha decay, alpha disintegration
The radioactive transformation of a nuclide by alpha-particle emission. The decay product is the nuclide having a mass number four units smaller and an atomic number two units smaller than the original nuclide.

alpha disintegration energy, Q_α

1. The *disintegration energy* of an alpha disintegration process. It is equal to the sum of the kinetic energy of the alpha particle, E_α, and the kinetic energy of recoil of the product atom, E_R. If M_α and M_R are the masses of the alpha particle and the recoil atom, respectively, then

$$E_\alpha = \frac{M_R}{M_R + M_\alpha} Q_\alpha$$

and

$$E_R = \frac{M_\alpha}{M_R + M_\alpha} Q_\alpha$$

2. Often, implicitly, the **ground state alpha disintegration energy,** which is the total energy evolved, including the energy of gamma and associated radiations, when the disintegrating and product nuclei in their ground states; $Q_{\alpha o}$.

alpha emitter
A radionuclide that undergoes transformation by alpha-particle emission.

alpha particle

1. A positively charged particle emitted from a nucleus and composed of two protons and two neutrons. It is identical in all measured properties with the nucleus of a helium atom.
2. By extension, the nucleus of a helium atom ($Z = 2$, $A = 4$), especially when it is in rapid motion, as when artificially accelerated. *(See binding energy, alpha particle)*

alpha-particle model of nucleus
A nuclear model for which the basic structural unit is the alpha particle. It is assumed that as many of the nucleons as possible are grouped together to form alpha particles and that the remaining nucleons move about somewhat freely. The model is most successful for light nuclei consisting of the same even number of neutrons and protons. Such a nucleus is referred to as an **alpha-particle nucleus.**

alpha-particle spectrum
(See spectrum)

alpha radiation
Alpha particles emerging from radioactive atoms.

alpha ray
A synonym for *alpha particle.*

alpha-ray spectrometer
An instrument used to determine the energy distribution of alpha particles. *(See spectrometer)*

alpha uranium
(See uranium)

aluminum (Al)
A metal, thirteenth element in the atomic series, important as a structural material in low-temperature nuclear reactors because it has a fairly low neutron-capture cross section and is abundant, easily worked, and ductile.

americium (Am)
An element, atomic number 95, discovered by G. T. Seaborg, R. A. James and L. O. Morgan in 1945. They synthesized 475y Am^{241} by (α,n) reaction with U^{238} followed by beta decay of the resulting Pu^{241}.

Am^{241} is also available in neutron irradiated plutonium as the result of successive neutron capture by Pu^{239}. The element was named for the Americas. Several other synthetic isotopes have been prepared. The usual oxidation state is + 3; the species AmO_2^+, AmO_2^{++}, AmO and AmO_2 are also known.

amu
The symbol for atomic mass unit. *(See atomic mass)*

anaphase (radiobiology)
A stage in nuclear division, either mitotic or meiotic, in which the paired chromosomes are separated toward opposite poles of the spindle.

androgenesis (biology)
Development of an egg with paternal (sperm) chromosomes only, accomplished by radiation or other type of damage to the egg nucleus before fertilization.

anemia (biology)
A condition in which the blood is deficient either in quantity or quality. The deficiency in quality may consist of diminution of the amount of hemoglobin or in diminution of the number of red blood corpuscles.

angle straggling
(See straggling)

angstrom, Å
A unit of length, used chiefly in expressing short-wavelengths. It equals 10^{-10} meters or 10^{-8} centimeters.

angular distribution
The distribution in angle, relative to an experimentally specified direction, of the intensity of particles or photons resulting from a nuclear or an extra-nuclear process. Commonly, the specified direction is that of an incident beam, and the angular distribution is that of particles which are scattered or are the products of nuclear reactions. In such cases, the angular distribution in the *laboratory system* will depend upon the energy of the incident particles. Alternatively, the specified direction might be that of an applied field, or a direction of polarization, or the direction of emission of an associated radiation.

angular momentum (atomic and nuclear physics)
The angular momentum of an elementary particle or of a nuclear or atomic system of such particles. This angular momentum may be that of the orbital motion of the particles or may be associated with the spinning of a particle about its own axis. For an elementary particle, the angular momentum associated with its axial rotation is called the **intrinsic angular momentum** or **(intrinsic) spin**; however, the term **spin** is also used for the total angular momentum (sum of orbital and intrinsic) of a nucleus. Both kinds of angular momentum are quantized in units of $\hbar$; the orbital angular momentum must be an integral multiple of $\hbar$, while the intrinsic spin of most elementary particles is $\frac{1}{2}\hbar$. The components of both kinds of angular momentum in a particular direction are also quantized.

annealing (metallurgy)
1. A process involving heating and cooling, usually applied to induce softening. The term also refers to treatments intended to alter mechanical or physical properties, produce a definite microstructure, or remove gases.
2. The process of heating, whereby the properties changed by radiation are partially or wholly restored.

annihilation
1. A process in which a pair of antiparticles meet and convert spon-

taneously into one or more photons; it is the inverse of *pair production*. The commonest example is the annihilation of an electron and a positron, the rest masses of which are converted into (usually) two 0.511-Mev photons according to the principle of *mass-energy equivalence*.

2. The conversion of rest mass into electromagnetic radiation.

annihilation radiation
Electromagnetic radiation produced by the union, and consequent annihilation, of a positron and an electron. Each such annihilation usually produces two, rarely one or three, photons. These photons have properties identical with those of gamma rays, and accompany the decay of all positron-emitting radioactive substances. A positron and an electron are most likely to unite when their relative velocity is small; hence the energy available for the annihilation radiation will be that of the rest masses of the electron, $2m_ec^2$[= 1.02 Mev], and the process will usually result in the production of two oppositely-directed photons, each of energy 0.51 Mev.

anticoincidence
(See coincidence)

anticoincidence circuit (instrumentation)
A circuit with two input terminals which delivers an output pulse if one input terminal receives a pulse, but delivers no output pulse if pulses are received by both input terminals simultaneously or within an assignable time interval.

antineutrino

1. The kind of *neutrino* presumed to be emitted during radioactive decay by β^+ emission or electron capture. It bears to the neutrino, which is emitted in β^- emission, the same relationship as does the positron to the electron. Formally, the antineutrino may be regarded as a hole in the negative-energy Dirac sea of neutrinos. It may be that the neutrinos are identical. Since there is no possibility of charge differentiation, any differentiation between these two as yet undetected particles must depend on properties such as the sign of the ratio of magnetic moment to angular momentum. The symbol ν^* is sometimes used for the antineutrino.
2. Sometimes the terms antineutrino and neutrino are used in the reversed sense; that is, the neutrino is said to accompany β^+ emission and the antineutrino β^- emission.

anti-proton, negative proton
An elementary particle that differs from a *proton* only in that its charge is negative. Its existence was predicted theoretically and recently has been confirmed experimentally.

aperture (accelerator)
(See relative aperture)

appearance potential (mass spectrometer)
The minimum energy that the electron beam in the ion source must have in order to produce ions of a particular species when a molecule is ionized.

area monitor (instrumentation)
Any device used for detecting and/or measuring radiation levels at a given location for warning or control purposes.

areal density
A synonym for *surface density*.

argon age
(See age)

artificial radioactivity

1. A term used to denote the phenomenon of radioactivity produced by particle bombardment or electromagnetic irradiation.
2. The radioactivity of synthetic nuclides. *(See induced radioactivity)*

associated corpuscular emission

The full complement of secondary charged particles (usually limited to electrons) associated with an x-ray or gamma-ray beam in its passage through matter. The full complement of electrons is obtained after the radiation has traversed sufficient air to bring about equilibrium between the primary photons and secondary electrons. Electronic equilibrium with the secondary photons is intentionally excluded. (In the definition of *roentgen*, the matter considered is air.)

astatine (At)

An element, atomic number 85, discovered in 1940 by D. R. Corson, K. R. MacKenzie and E. Segrè. They synthesized 7.5*h* At^{211} and later 8.0*h* At^{210} by helium ion bombardment of bismuth. Other shorter-lived isotopes are known. The element was named after the Greek word *astatos*, meaning unstable, with the ending *-ine* characteristic for a halogen. In its chemical behavior it seems to be more electropositive than iodine.

atomic absorption coefficient

(See absorption coefficient, μ)

atomic energy

In popular usage, *nuclear energy* released in sufficient quantity to be of engineering interest.

atomic mass, amu

The mass of a neutral atom of a nuclide. It is usually expressed in terms of the physical scale of atomic masses, that is, in atomic mass units. The **atomic mass unit,** amu, is exactly one-sixteenth of the mass of a neutral atom of the most abundant isotope of oxygen, O^{16}; 1 amu = 1.657×10^{-24} gm = 931 Mev = 0.999728 awu. *(See atomic weight; mass number)*

atomic number, Z

An integer that expresses the positive charge of the nucleus in multiples of the electronic charge *e*. It is the number of electrons outside the nucleus of a neutral atom and, according to present theory, the number of protons in the nucleus. The **effective atomic number** is a number calculated from the composition and atomic numbers of a compound or mixture. An element of this atomic number would interact with photons in the same way as the compound or mixture. Various formulae for this number have been developed, of which the following are perhaps best known:-

Spier: Based on theoretical considerations involving absorption and scattering coefficients (Brit. J. Radiol. *19*, p. 42, 1946)

$$Z = \text{eff. at. no.}$$
$$= (a_1 Z_1^{2.94} + a_2 Z_2^{2.94} + \ldots)^{\frac{1}{2.94}}$$

where Z_1, Z_2, etc., are atomic numbers of individual constituents, and a_1, a_2, etc., the fractional electron contents of elements Z_1, Z_2, etc., in the compound.

Fricke and Glasser: Based on theoretical considerations of photoelectron production (Fortsch. a.d. Gebiete der Roentgenstrahlen *33*, p. 243, 1925)

$$Z = \sqrt[3]{\frac{a_1 Z_1^4 + a_2 Z_2^4 + \ldots\ldots\ldots}{a_1 Z_1 + a_2 Z_2 + \ldots\ldots\ldots}}$$

where Z_1, Z_2, etc., are the atomic numbers of the constituents, and a_1, a_2 their fractions by weight.

atomic power
A popular synonym for *nuclear power*. *(See atomic energy; nuclear energy)*

atomic ratio
Ratio of quantities of different substances in terms of number of atoms of each.

atomic stopping power
(See stopping power)

atomic weight, awu
The weighted mean of the masses of the neutral atoms of an element expressed in atomic weight units. Unless otherwise specified it refers to a naturally occurring form of the element. The **atomic weight unit**, awu, is exactly one-sixteenth of the weighted mean of the masses of the neutral atoms of oxygen of isotopic composition found in fresh lake or rain water; $1 \text{ awu} = 1.660 \times 10^{-24}$ gm = 1.000272 amu. The experimentally determined ratio of the atomic weight unit to the *atomic mass unit* is called the **atomic mass conversion factor.** The value of this factor is uncertain in the seventh significant figure because of variations in the isotopic composition of oxygen from different natural sources. In the future its value, and hence that of the atomic weight unit, may be rendered exact by definition. *(See atomic mass)*

atomic weight, chemical scale, is the average weight of the atoms of an element (of isotope distribution found in nature) referred to the weight of exactly 16 for the average weight of the atoms of oxygen of isotope distribution found in fresh lake or rain water. The value may be computed from atomic weights on the physical scale by division by the factor 1.000272.

atomic weight, physical scale, is the weight of an atom or the average weight of a mixture of atoms of an element referred to the exact value 16 for the principle isotope of oxygen, O^{16}. Atomic weights on the physical scale are expressed in atomic mass units, amu. They may be computed from the atomic weights on the chemical scale by multipliby the factor 1.000272.

attenuation

1. (Radiation theory) The reduction in the flux density, or power per unit area, with distance from the source; it may be due to absorption, to scattering, or to both processes.
2. (Nuclear physics) The reduction in the intensity of radiation upon passage through matter; in general, it is due to a combination of scattering and absorption.

The term is best used in a sense that excludes the geometric decrease of intensity with distance from the source (inverse-square effect); the attenuation then depends only on the nature of the radiation and of the material traversed.

attenuation factor
A measure of the opacity (*see opaque*) of a layer of material for radiation traversing it; the ratio of the incident intensity to the transmitted intensity. It is equal to I_0/I, where I_0 and I are the intensities of the incident and emergent radiation, respectively. In the usual sense of *exponential absorption* ($I = I_0 e^{-\mu x}$), the attenuation factor is $e^{+\mu x}$, where x is the thickness of the material and μ is the *absorption coefficient.*

Auger effect
A nonradiative transition of an atom from an excited electronic energy state to a lower state with the emission of an electron. The term usually refers to the x-ray region of energy states. The final state corresponds to one higher degree of ionization

than does the initial state. The effect is an alternative process to the transition to a lower state having the same degree of ionization with the emission of an x-ray photon and thus is analogous to the internal conversion of a nuclear transition. The ejected electron has kinetic energy equal to the difference between the energy of the x-ray photon of the corresponding radiative transition and the binding energy of the ejected electron. An electron so ejected is known as an **Auger electron.** The **Auger yield** for a given excited state of an atom of a particular element is the probability of de-excitation by the Auger effect rather than by x-ray emission; it is the difference between unity and the *fluorescence yield* for that state, and also equals the sum of the Auger yields for the various possible Auger transitions from that state. The **Auger coefficient** is the ratio of Auger yield to fluorescence yield, or the ratio of the number of Auger electrons to the number of x-ray photons emitted from a large number of similarly excited atoms.

Auger shower
A synonym for *extensive shower.*

Auger yield
The ratio *a/b* where *a* is the number of Auger electrons emitted and *b* is the number of events resulting in an inner shell electron vacancy. *(See Auger effect)*

augmentation distance
The distance between the extrapolated boundary and true boundary of a nuclear reactor.

autoclave
An apparatus for conducting reactions under pressure and usually at elevated temperatures.

automatic control system (instrumentation)
Any operable arrangement of one or more automatic controllers connected in closed loops with one or more processes. *(See feedback control system)* [For automatic control or feedback control terminology, refer to ASME Standard 105, "Automatic Control Terminology," 1954, and "IRE Standards on Terminology for Feedback Control Systems," IRE Proceedings, Vol. 44, No. 1, January 1956].

autoradiograph (radioautograph)
Record of radiation from radioactive material in an object, made by placing its surface in close proximity to a photographic emulsion.

autoradiography
The production of autoradiographs.

avalanche
The multiplicative process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules. This cumulative increase of ions is also known as **Townsend ionization** or a **Townsend avalanche.**

average life (mean life)
The average of the individual lives of all the atoms of a particular radioactive substance. It is 1.443 times the radioactive half-life.

awu
The symbol for atomic weight unit. *(See atomic weight)*

azeotrope (chemical engineering)
A liquid mixture which, on boiling at constant pressure, yields a vapor the same in composition as itself and consequently does not change in composition or boiling point as vaporization proceeds. **Azeotropic distillation** is separation by distillation of a relatively volatile azeotrope formed from an added compound and one of the constituents of the original mixture.

B

"B" neutrons
Neutrons of such energy that they are strongly absorbable by gold, that is, of energy in the neighborhood of 7 ev. The term is now obsolete.

back scatter, backscattering

1. The deflection of particles or of radiation by scattering processes through angles greater than 90° with respect to the original direction of motion.
2. (Chemistry) The process of scattering or reflecting into the sensitive volume of a measuring instrument radioactive radiations originally having no positive component of motion in that direction. It is dependent on the nature of the mounting material, the sample, the type and energy of the radiations, and the particular geometrical arrangement.
3. (Biophysics) Scattering of radiation in a generally backward direction. In radiation therapy it is particularly applied to radiation scattered back to the skin from underlying tissues.
   (*See scattering*)

background
Ever-present effects in physical apparatus above which a phenomenon must manifest itself in order to be measured. "Background" can take various forms, depending on the nature of the measurement. In electrical measurements of radioactivity and nuclear phenomena, the term usually refers to those undesired counts or currents that arise from cosmic rays, local contaminating radioactivity, insulator leakage, amplifier noise, power-line fluctuations, and so on. In nuclear work and photographic emulsions, the term refers to developable grains unrelated to the tracks under investigation.

background counts
(See counts, background)

baffle plate
A tray or partition placed in a tower, heat exchanger or other process equipment to direct or to change the direction of the flow of fluids.

band
The set of closely spaced spectral lines produced by molecules of one kind when there is a transition between two electronic-vibrational states possessing rotational fine structure. The individual lines, which result from transitions between two particular states of rotation of the molecule, can sometimes be resolved with a spectroscope of high resolving power, especially for gaseous molecules. In some cases the lines are crowded together at one edge of the band, called the **band head,** and their separation increases with distance from it. In many cases, especially for liquids and solids, the bands are inherently smeared and cannot be resolved; then there is no definite edge.

band spectrum
(See spectrum)

barn, b
A unit of area used in expressing a nuclear cross section. 1 barn = 10^{-24} cm^2. Cross sections per atom are customarily measured in barns.

barrier
(See potential, nuclear)

barrier, Coulomb
(See potential, nuclear)

barrier, diffusion
(See diffusion barrier)

batch distillation
A distillation in which a given quantity of material is charged into a still, and the distillation is conducted without additional charge to the still.

batch process
A process in which the feed is introduced as discrete charges, each of which is processed to completion separately.

beam
A unidirectional or approximately unidirectional flow of electromagnetic radiation or of particles.

beam hole
Hole through the shield and usually through the reflector of a reactor to permit the escape of a beam of radiation, in particular a beam of fast neutrons, for experimental purposes.

before-and-after test (reactor engineering)
Irradiation test in which the properties of a specimen are measured before insertion into and after its removal from a reactor.

benign tumor
(See neoplasm)

berkelium (Bk)
A name proposed for element number 97, whose discovery was announced by S. G. Thompson, A. Ghiorso and G. T. Seaborg in 1950. They produced an isotope of 4.6*h* half-life, probably Bk^{243}, by helium ion bombardment of Am^{241}. The oxidation states +3 and +4 are known.

Bernoulli's equation (binomial distribution)
An equation expressing the probability that exactly n counts will be obtained in a single period when there are N atoms present each with the probability p of disintegrating and being counted in that period.

$$P_n = \frac{p^n(1-p)^{N-n}\,N!}{n!\,(N-n)!}$$

beryl
A mineral, silicate of beryllium and aluminum, $Be_3Al_2(SiO_3)_6$. The chief ore of beryllium.

beryllia
Oxide of beryllium, BeO, useful as a moderator or reflector. Its ceramic nature and low neutron-capture cross section make it useful also as material for fabricating some reactor parts.

beryllium (Be)
A metal, fourth element of the atomic series, of importance as a moderator and reflector in nuclear reactors because of its low neutron-absorption cross section, high slowing-down power, and high thermal conductivity. Its oxide, BeO, sometimes called *beryllia*, is valuable in the same connection. Beryllium and its compounds must be fabricated under controlled conditions because of its highly toxic nature.

beta decay, beta disintegration
Radioactive transformation of a nuclide in which the atomic number changes by ± 1 and the mass number remains unchanged. Increase of atomic number occurs with negative beta particle emission, decrease with positive beta particle (*positron*) emission or upon *electron capture*.

beta disintegration, Q_β

1. The *disintegration energy* of a beta-decay process. For negatron emission it is equal to the sum of the kinetic energies of the beta particle, the neutrino, and the recoil atom (usually negligible), and is obtained experimentally from the maximum energy of the beta-particle spectrum. For positron emission, the energy equivalence of two electron rest masses must be added to the aforementioned sum, since the products include the positron and one negative electron in addition to the neutral product atom; the energy equivalent to their masses ultimately appears as radiant energy of *annihilation radiation*. For electron capture, the disintegration energy is equal to the sum of the kinetic energy of the neutrino and the electronic excitation energy of the product atom (usually, the binding energy, in the neutral product atom, of an electron equivalent to that which was captured).
2. Often, implicitly, the **ground-state beta disintegration energy,** which is the total energy released in a beta transition between isobars in their ground states; symbol Q_{β_0}. It includes the energies of any gamma and associated radiations following the beta process itself.

beta emitter
A radionuclide that disintegrates by beta particle emission.

beta particle
A negative electron or a positive electron (*positron*) emitted from a nucleus during beta decay. The symbols β, β^- and β^+ are reserved for electrons of nuclear origin.

beta ray
A synonym for *beta particle*.

beta-ray spectrometer
An instrument used to determine the energy distribution of beta particles and secondary electrons.

beta-ray spectrum
(See spectrum)

beta uranium
(See uranium)

betatron, induction accelerator
A device for accelerating electrons by means of magnetic induction.

Bev
The symbol for *billion electron volt*, or 10^9 ev.

bevatron
(See synchrotron)

billion electron volt, Bev
A unit of energy, symbol Bev, equal to 10^9 ev. (*See electron volt*)

binary scaler
(See scaler)

binding energy
The **nuclear binding energy** is the energy that would be required to separate an atom of atomic number Z and mass number A into Z hydrogen atoms and A-Z neutrons. It is the energy equivalent of the difference between the sum of the masses of the product particles (hydrogen atoms and neutrons) and the mass of the atom. It includes the effect of electronic binding (total electron

binding energy). Except for the lightest nuclides, it is approximately equal to 8A Mev. The energy required to remove a single neutron from a nucleus is the **neutron binding energy**. The neutron binding energy for a nuclide Z^A is equal to the energy released when a neutron is added to the nuclide Z^{A-1}. Most known neutron binding energies are in the range 5 to 12 Mev, although that for H^2 is 2.23 Mev, that for Be^9 is 1.67 Mev, that for He^4 is 20.58 Mev, and that for He^5 is negative by about 0.8 Mev. The energy required to remove a single proton from a nucleus is the **proton binding energy**. The proton binding energy for a nuclide Z^A is equal to the energy released when a proton is added to the nuclide $(Z-1)^{A-1}$. Most known proton binding energies are in the range 5 to 12 Mev, although that for H^2 is 2.23 Mev, that for H^4 is 19.81 Mev, and those for Li^5 and B^9 are negative. **The total electron binding energy** is the energy required to remove all of the electrons of an atom to infinite distance from the nucleus and from each other, leaving only the bare nucleus. It is equal to the sum of the *ionization potentials* (1st, 2nd, . . . , Zth) of the atom and is approximately equal to $RZ^{12/5}$, which expression yields, for example, 0.70 Mev for uranium.

binding energy, alpha particle
The energy required to remove an alpha particle from a nucleus. For spontaneous alpha emitters, it is the negative of the *ground state alpha disintegration energy*. For most light nuclides the alpha particle binding energy is positive and equal to several Mev. For nuclides of mass number $\sim$125, it is approximately zero. For nuclides of mass number $\sim$150 to 200, it is negative by $\sim$1 to 3 Mev, but the lifetimes for alpha disintegration are generally too long for detection of alpha activity. For most nuclides of mass number exceeding 200, the alpha particle binding energy is negative by $\sim$4 to 8 Mev, leading to observable alpha activity.

binding energy, electron
A synonym for *ionization potential*.

biologic effectiveness of radiation (relative), **RBE**
(See relative biological effectiveness of radiation)

biologic half-life (radiobiology)
The time in which a living tissue, organ, or individual eliminates, through biologic processes, one-half of a given amount of a substance which has been introduced into it. *(See half-life)*

biological hole
Cavity in a nuclear reactor to permit placing animals or plants near the active section for experiments on the effects of radiation or neutron bombardment.

biological shield
A shield used to reduce the intensity of radiation transmitted to an amount permissible physiologically, to protect personnel from the effects of particles or radiation, usually from a nuclear reactor.

biophysics
The study of phenomena of living organisms by physical methods. The study of physical phenomena exhibited by living organisms or parts thereof.

biscuit (metallurgy)
1. The solid metallic product which results from reduction of a metallic compound by an active metal in a bomb or furnace.
2. An upset blank from which a forging is produced.

bismuth (Bi)
A metal, eighty-third element in the atomic series, atomic weight 209.00. The naturally occurring stable element consists of one isotope of mass number 209, the heaviest stable nuclide. Bi^{209} is the final product in the decay of the neptunium series. It is a brittle, heavy metal with low melting point and low capture cross section for neutrons. The last two properties have caused it to be considered, either alone or in combination with other metals, for liquid-metal cooling of nuclear reactors. Also, its high absorption for gamma rays makes it useful in some experimental arrangements as a filter or window to reduce gamma rays but transmit neutrons.

black
(See opaque)

blanket
A layer of fertile material placed external to the core of a reactor.

blister (metallurgy)
A defect on the surface of a metal in the form of a raised spot or nodule which is produced during or following electroplating, heat treating, other processing, or corrosion. The blister may contain gaseous or solid reaction products of chemical reagents, or in some instances may be composed of solid metal.

blood count (hematology)
Red count is the number of red corpuscles per cubic millimeter of blood. **Total white count** is the number of white corpuscles per cubic millimeter of blood. **Differential white count** is the number of each variety of white corpuscles in a count of 100. (The two most numerous varieties are *polymorphonuclear leucocytes* and *lymphocytes*.) **Platelet count** is the number of platelets per cubic millimeter of blood.

body-centered cubic (metallurgy)
A crystal structure characterized by a cubic unit cell with an atom in each corner and an atom in the center of the cube. Two atoms are associated with each cell.

Bohr magneton
A unit of magnetic moment used in specifying the magnetic moment of an atomic particle or system of particles:

1. The **electronic Bohr magneton** μ_0, given by $\mu_0 = eh/4\pi m_e c = 9.27 \times 10^{-21}$ erg gauss^{-1}, where m_e is the rest mass of the electron. If not otherwise specified, Bohr magneton refers to the electron Bohr magneton.
2. The **nuclear Bohr magneton** or nuclear magneton, μ_2, given by $\mu_2 = eh/4\pi Mc = \mu_0/1836$ erg gauss^{-1}, where M is the rest mass of the proton.

Bohr radius

1. The radius r_1 of the orbit of lowest energy in the Bohr model of the hydrogen atom; it is given by

$$r_1 = \frac{h^2}{4\pi^2 m_e e^2}$$

2. Occasionally, the radius r_n of any one of the permissible orbits in the Bohr model of the hydrogen atom; it is given by

$$r_n = \frac{n^2 h^2}{4\pi^2 m_e e^2} = n^2 \times 0.529 \times 10^{-8} \text{ cm},$$

where n is the principal quantum number, which may have any positive integral value.

Boltzmann equation
The detailed particle conservation equation, based on the description of individual collisions. In reactor physics, neutron-neutron collisions are ignorable.

bombard
To direct a stream of high energy particles or photons against a target. Sometimes loosely used for irradiation in a nuclear reactor.

bombardment damage
Damage from bombardment by particles as distinguished from photons. *(See radiation damage)*

bone seeker (radiobiology)
Any compound or ion which migrates *in vivo* preferentially into bone.

boron (B)
An element, fifth of the atomic series, important in instruments for detecting and measuring neutrons because the isotope B^{10}, which has a relative abundance of 18.8% in natural boron, on absorbing a neutron breaks into two charged particles (He^4 and Li^7) which can be detected easily. The cross section is inversely proportional to neutron velocity. Because of its high absorption of neutrons, boron may be used (e.g., in the form of boron steel) as a control absorber in thermal nuclear reactors. It also is useful as a constituent of neutron shields because only relatively few weak gamma rays are emitted upon capture of a neutron.

boron chamber
An ionization chamber lined with boron or boron compounds and/or filled with a gaseous boron compound such as BF_3.

boron counter tube
A counter tube filled with BF_3 and/or having electrodes coated with boron or boron compounds used for detecting slow neutrons by the (n,α) reaction of B^{10}.

Bose-Einstein statistics
(See quantum statistics)

boson
(See quantum statistics)

bottoms
The material drawn off from the bottom of a tower or still; any residue accumulating in the bottom of a process vessel.

bound water
In the drying of solids, water which is chemically combined.

boundary layer
The region in a fluid adjacent to an interface wherein the velocity is significantly different from that of the main stream.

Bragg angle
The angle θ appearing in the *Bragg law.*

Bragg curve
A curve showing the average number of ions per unit distance along a beam of initially monoenergetic ionizing particles, usually alpha particles, passing through a gas. The curve has a "tail" at the low-energy end as a result of straggling. (fig. 2)

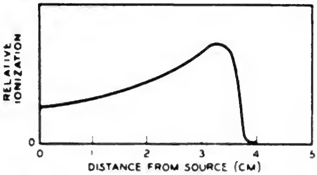

Fig. 2 Bragg curve for Po^{210} alpha particles in dry air at 15°C and 1 atm.

Bragg law
The statement of the condition under which a crystal will reflect a beam of x-rays with maximum intensity; the law is also valid for the reflection of de Broglie waves associated

with electrons, protons, neutrons, and so forth. *(See de Broglie relation)* It is expressed by the equation $n\lambda = 2d \sin \theta$, where λ is the wavelength, d the distance between crystal planes, n an integer denoting the order of diffraction, and θ the angle of incidence and also of reflection; θ is measured relative to the crystal planes rather than to the normal as is the case for optical reflection.

Bragg rule
An empirical rule, according to which the mass stopping power of an element for alpha particles is inversely proportional to the square root of the atomic weight, or the atomic stopping power is directly proportional to the square root of the atomic weight. The rule therefore leads to relations between the stopping powers of different elements for alpha particles. It holds for other charged particles to the same degree of approximation as for alpha particles. *(See stopping power)*

branch
A product or series of products resulting from one mode of decay of a radioactive nuclide exhibiting two or more such modes.

branching (radioactivity)
The occurrence of two or more modes by which a radionuclide can undergo radioactive decay. For example, RaC can undergo α and β^--decay, Cu^{64} can undergo β^-, β^+, and electron capture decay. An individual atom of a nuclide exhibiting branching disintegrates by one mode only. The fraction disintegrating by a particular mode is the **branching fraction** for that mode. The **branching ratio** is the ratio of two specified branching fractions. *(Syn. multiple decay; multiple disintegration)*

branching ratio

1. The ratio between the fraction of parent atoms decaying by one mode to that decaying by another. *(See branching)*
2. Obsolete term for fission yield.

brazing (metallurgy)
The process of joining metals by the fusion and solidification of a metal or alloy whose melting point is lower than those of the metals being joined. The fusion may be accomplished by means of a torch while the brazing alloy is fed in the form of rod; or the work may be assembled with the solid brazing alloy in the form of wire or sheet placed at the appropriate points, and the entire assembly heated in a furnace or other device. This term is usually applied only to joining with metals or alloys which melt above 800° F (427° C), while the analogous process using lower-melting nonferrous alloys is called **soldering**.

break, chromatid (biophysics)
The transverse break of one or both chromatid threads after the longitudinal division of the chromosome. Breakage at the same level of the sister threads is called an isochromatid break.

break, chromosome
(See chromosome break)

break point
(See break-through)

break-through (chemical engineering)
That point in an adsorption cycle at which the effluent begins to show a marked increase in concentration of the substance being adsorbed.

breeder
(See converter)

breeding gain (reactor theory)
Breeding ratio minus one.

breeding ratio (reactor theory)
The number of fissionable atoms produced per fissionable atom destroyed.

Breit-Wigner formula
An equation relating the cross section σ of a particular nuclear reaction to the energy E of the incident particle and the energy E_0 of a *resonance level* of the compound nucleus when E is close to E_0. In the special case where only one resonance level is involved, the Breit-Wigner formula is

$$\sigma(a,b) = (2l+1)\pi \bar{\lambda}^2 \frac{\Gamma_a \Gamma_b}{(E-E_0)^2+(\frac{1}{2}\Gamma)^2},$$

where $\sigma(a,b)$ is the cross section for the reaction involving the capture of particle a and the emission of particle b, Γ_a is the partial width of the energy level for the mode of disintegration in which the incident particle is re-emitted without loss of energy, Γ_b is the partial width of this energy level for the mode of disintegration in which particle b is emitted, Γ is the total width of the energy level, $\bar{\lambda} = \lambda/2\pi$, where λ is the de Broglie wavelength of the incident particle, and l is the orbital angular momentum quantum number of the incident particle. (*See level width*)

bremsstrahlung
1. The production of electromagnetic radiation by the acceleration that a fast charged particle (usually an electron) undergoes when it is deflected by another charged particle (usually a nucleus). The spectral distribution is continuous, the well-known continuous x-radiation being a prominent example. For very energetic electrons (above about 50 Mev), the energy loss by radiation far exceeds that by ionization as a stopping mechanism in matter; this process is sometimes called **outer bremsstrahlung** in order to distinguish it from *inner bremsstrahlung*. A very weak electromagnetic radiation with a continuous spectral distribution is sometimes observed from beta-active substances; this is due to one or both types of bremsstrahlung.
2. Sometimes, the radiation resulting from the bremsstrahlung process.

brevium
(See uranium X_2)

Brinell hardness
(See hardness)

Btu
"British thermal unit": The quantity of heat required to increase the temperature of one pound of water one degree Fahrenheit at atmospheric pressure; approximately 252 gram-calories.

bubble cap
A device resembling an inverted cup with serrated or slotted edges employed in conjunction with a plate in a column; it serves to distribute vapors rising from the plate beneath through the liquid seal on the plate in question, thus improving liquid-vapor mass transfer.

bubble plate
In a distillation or absorption column, a tray or plate equipped with bubble caps and an overflow pipe.

buckling (reactor theory)
A measure of the curvature of the neutron density distribution. In a bare homogeneous reactor, the **geometric buckling** is that curvature needed for the reactor to be critical,

as determined from its geometrical configuration, whereas the **material buckling** is the curvature obtainable in that material.

bulk test (reactor engineering)
Test of a shield sample having high attenuation, usually requiring a large sample.

burial ground, graveyard (reactor engineering)
A place for burying unwanted radioactive objects to prevent escape of their radiations, the earth acting as a shield. Such objects must be placed in watertight, non-corrodible containers so that the radioactive material cannot be leached out and get into an underground water supply.

burn-up (reactor engineering)
Destruction of atoms by neutrons in reactor operation; the term can be applied to fuel or other materials. (*See depletion*)

burnable poison
A substance with high neutron capture cross section which has a capture reaction product of low capture cross section and which is purposely put into a fission reactor to influence the long-term reactivity variations.

burst
In cosmic ray studies, an exceptionally large electric pulse observed in an ionization chamber, signifying the simultaneous arrival or emission of several or many ionizing particles. Such an event may be caused by a *cosmic ray shower* or by a *spallation* disintegration of the type that can produce a *star*.

C

"C" neutrons
Neutrons of such energy that they are strongly absorbable in cadmium. "C" neutrons have energies from zero up to about 0.3 electron volts.

cadmium (Cd)
A metal, forty-eighth element in the atomic series, of importance as a control absorber and material for special shields because of its very high capture cross section for neutrons with energies of less than 0.5 electron volt. It occurs in the rather rare mineral greenockite but is obtained practically as a low-quality by-product from ores of zinc.

cadmium ratio
The ratio of the neutron-induced saturated activity in an unshielded foil to the saturated activity of the same foil when it is covered with cadmium.

calcium age
(See age)

californium (Cf)
A name proposed for element number 98 whose discovery was announced by S. G. Thompson, K. Street, A. Ghiorso and G. T. Seaborg in 1950. They produced an isotope of 45*m* half-life, Cf^{245}, by bombardment of Cm^{242} with helium ions. The only oxidation state known is +3.

calutron
A production isotope separator of the electromagnetic type based on the 180° focusing Dempster mass spectrograph.

can
(See jacket)

canal (reactor engineering)
A water-filled trench or conduit associated with a nuclear reactor, used for removing and sometimes storing radioactive objects taken from the reactor. The water acts as shield against radiation but permits objects in the canal to be moved and inspected with relative ease.

cancer (biology)
Any malignant *neoplasm.*

canyon (reactor engineering)
A long, narrow space enclosed with heavy shields, constituting the major part of a building used for certain types of radiochemical plants, such as plants for reprocessing used fuel.

capillary theory of separation (isotopes separation)
A theory of the separation of gases by flow through a porous medium, based on the concept of momentum transfer. The actual porous medium is treated as equivalent to a bundle of parallel capillary tubes. (Physical Review 75, 1050, 1949.)

capture
A process in which an atomic or nuclear system acquires an additional particle; for example, the capture of electrons by positive ions, of electrons by nuclei, or of neutrons by nuclei. The gamma rays emitted after such capture are called **capture gamma rays**. *(See electron capture; capture, radiative)*

(Reactor theory) **radiative capture,** capture cross section; **absorption capture,** neutron capture.

capture, radiative
A nuclear capture process whose prompt result is the emission of electromagnetic radiation only. Examples of radiative capture processes are (n,γ) and (p,γ) reactions.

capture efficiency (synchro-cyclotron)
The ratio of the time available during a frequency modulation cycle for starting particles into stable orbits to the total time for repetition of the frequency-modulation cycle.

capture gamma
Gamma radiation emitted promptly upon the capture of a neutron by a nucleus.

carbon (C)
An element, sixth in the atomic series. Its low neutron-capture cross section and low atomic weight make it valuable as a moderator (*see graphite*). The artificially produced isotope C^{14} is radioactive and much used as a tracer in biological and organic chemical research.

carbon cycle
A series of thermonuclear reactions, with the release of energy, that presumably occurs in the sun and other stars; namely,

$C^{12} + H^1 \longrightarrow N^{13} + \gamma$, followed by
  $N^{13} \longrightarrow C^{13} + \beta^+ + \nu$,
$C^{13} + H^1 \longrightarrow N^{14} + \gamma$,
$N^{14} + H^1 \longrightarrow O^{15} + \gamma$, followed by
  $O^{15} \longrightarrow N^{15} + \beta^+ + \nu$,
$N^{15} + H^1 \longrightarrow C^{12} + He^4$.

Completion of the cycle restores the C^{12}, with which it began. The net accomplishment is the synthesis of four hydrogen atoms into a helium atom with attendant release of nuclear energy. *(See reaction, thermonuclear; proton-proton chain)*

carcinogenesis (biophysics)
Production of cancer.

carcinogenic (biophysics)
Capable of producing cancer.

carcinoma (biophysics)
Malignant neoplasm composed of epithelial cells.

carnotite
A mineral, hydrous vanadate of uranium, potassium, and other elements, $K_2O \cdot 2U_2O_3 \cdot V_2O_5 \cdot 3H_2O$. It occurs in Utah, Arizona, and Colorado as a minor constituent of sandstones and as a major constituent in certain sedimentary layers (particularly of former vegetable organic materials such as logs). It has been used as a source of radium and is important as an ore of uranium.

carrier (radiobiology)
An isotope or the normal isotopic mixture of an element, when mixed with radioactive atoms of the same element, in such a form that it undergoes the same chemical reaction. Carriers are often added deliberately for radiochemical purposes. (Chemistry)

1. A quantity of an element which may be mixed with radioactive isotopes of that element giving a ponderable quantity to facilitate chemical operations.
2. A substance in ponderable amount which when associated with a trace of another substance will carry the trace with it through a chemical or physical process, especially a precipitation process. If the added substance is a different element from the trace the carrier is called a non-isotopic carrier.
3. *See also hold-back agent*; *interchange; tracer.*

carrier-free
An adjective applied to one or more radioactive isotopes of an element in minute quantity, essentially undiluted with stable isotope carrier.

cascade (isotopes separation)
Any connected arrangement of separative elements whose effect is to multiply the isotope separation created by the individual element. A bubble plate tower is a cascade whose elements are the individual plates; a plant consisting of many towers in series and parallel is similarly a cascade whose elements may be considered to be either the towers or the individual plates. *(See stripper)*

cascade, ideal
The theoretical minimum number of separative elements necessary to perform a given separation.

cascade, square
A cascade in which the circulation is the same in each stage.

cascade shower
A type of *cosmic ray shower* that is initiated when a high-energy electron, in its passage through matter, produces one or more photons of energies comparable with its own. These photons then convert into electrons and positrons by the process of *pair production.* The secondary electrons in turn produce the same effects as the primary, and thus the number of particles increases along the way. The cascade shower of electrons and positrons builds up until the level of energy is so low that photon emission and pair production can no longer occur.

casket
(See coffin)

cataphoresis
(See electrophoresis)

cathode rays
1. A stream of electrons emitted by the cathode of a gas discharge tube when the cathode is bombarded by positive ions.
2. Any stream of electrons, as in a tube in which the source of the electrons is a heated filament.

cell
In a reactor which may be considered as a set of similar regions, one such region is called a cell.

cent
A unit of reactivity equal to one hundredth of a *dollar.*

center-of-mass system
A *frame of reference* that moves with the center of mass of the system. For example, if two particles of equal mass have a relative velocity v, the velocity of each with respect to the center-of-mass system is $v/2$, directed toward the midpoint of the particles. In experimental nuclear physics, the center-of-mass system is especially useful for describing scattering and induced nuclear reactions. If, for example, the angular distribution of the scattered or emitted particles is isotropic with respect to the center-of-mass system, it will be peaked toward the direction of motion when transformed to the *laboratory system.*

central force (nuclear)
(See nuclear forces)

ceramet
(See metal-ceramic)

ceramic reactor
A reactor constructed of fuel and moderator assemblies of high-temperature-resistant ceramic materials, such as metal oxides, carbides, or nitrides.

Cerenkov radiation
Visible light produced when charged particles traverse a transparent medium with a velocity exceeding the velocity of light in the medium. Such a situation exists, for instance, when a beam of electrons of velocity 0.8*c* (energy, 0.3 Mev) traverses glass of index of refraction 1.8. The manner of emission of Cerenkov radiation is analogous to that of the bow wave of a ship. The angle that the cone of luminescence makes with the direction of motion of the particle can be used to measure the velocity of the particle.

chain
(See radioactive series)

chain decay, chain disintegration
Synonyms for *series decay* and *series disintegration.*

chain fission yield
(See fission yield)

chain reaction
A reaction in which one of the agents necessary to the reaction is itself produced by the reaction so as to cause like reactions. In the neutron-fission chain reaction, a neutron plus a fissionable atom causes a fission resulting in a number of neutrons which in turn cause other fissions.

chance coincidence
(See coincidence)

channel (reactor engineering)
A passage, especially through the core of a reactor, for movement of heat-transfer fluid or to contain fuel slugs.

channeling (reactor theory)

1. The extra transmission of particles through a medium containing voids due to the presence of the voids.
2. The additional transmission of the material containing voids as compared to a homogeneous material with average density the same as the material with the voids.

channeling effect factor
Attenuation per unit length of equivalent homogeneous material divided by attenuation per unit length of the material containing voids.

characteristic radiation
(See radiation, characteristic)

characteristic x-rays
(See spectrum)

charge
The fissionable material or fuel placed in a reactor to produce a chain reaction. To assemble the charge in a reactor.

charger-reader (instrumentation)
Any auxiliary device used to charge and read pocket chambers or thimble ionization chambers. *(See also condenser r-meter)*

charpy test (metallurgy)
A type of impact test in which a notched specimen is supported freely at both ends and broken by the impact of a falling pendulum. The energy decrease of the pendulum, as determined by its decreased rise, is the measure of the impact strength. The test is of value in excluding notch-sensitive materials from consideration rather than in the design of structures.

chemical age
(See age)

chemical binding effect
The dependence of the neutron cross sections of a material on the chemical binding of the atoms composing the material.

chemical exchange
(See isotopic exchange)

chemical tracer
(See tracer)

chopper (instrumentation)
Any device for periodically interrupting a continuous current or flux. *(See vibrating contactor)*

chromatid (radiobiology)
One of the sister threads of the longitudinally divided chromosome prior to nuclear division.

chromatid break
(See break, chromatid)

chromatin (biophysics)
The material in the nucleus which stains deeply with basic dyes.

chromosome (biophysics)
One of a definite number of small dark-staining and more or less rod-shaped bodies situated in the nucleus of a cell and especially prominent at the time of cell division, when they duplicate and distribute equally to the daughter cells. They contain *genes* arranged along their length. The number of chromosomes in the somatic cells of an individual is constant (*diploid number*) while just half this number (*haploid number*) appears in germ cells; the number of chromosomes or diploid numbers, etc., within a species is usually constant.

chromosome, sex
A chromosome which has no truly similar homologue in the heterozygous sex and which is closely bound up with sex determination.

chromosome aberration
Any rearrangement of chromosome parts as a result of breakage and reunion of broken ends.

chromosome break (biophysics)
The transverse break of a chromosome before its longitudinal division into chromatid threads.

chromosome deletion
Loss of a section of a chromosome.

chromosome exchange (interchange and intrachange)
Joining in other than the original arrangement of the four ends resulting from two breaks in the chromosome, or from breaks in two chromosomes.

chromosome inversion
The appearance in a chromosome of a segment in which the normal linear order of the genes is reversed.

chromosome translocation
Change in position of a portion of a chromosome, either to different regions of the same chromosome or to another chromosome.

chromosomes, homologous
Chromosomes in which the same gene loci occur in the same sequence.

chronic exposure
(See exposure, chronic)

chronotron (instrumentation)
A device which utilizes a measurement of the position of the superposed loci of a pair of pulses on a transmission line to determine the time between the events which initiate the pulses.

chrysoberyl
A mineral, beryllium-aluminum oxide, $BeO \cdot Al_2O_3$, a possible ore of beryllium.

Chu
The symbol for centigrade heat unit. The quantity of heat required to increase the temperature of one pound of water one degree centigrade at

atmospheric pressure; approximately 454 gram-calories.

circuit (heat)
(See thermal cycle)

circulating reactor
A nuclear reactor in which the fissionable material circulates through the core. This ordinarily will involve the use of fissionable material in fluid form or in small particles suspended in a fluid.

clad (reactor engineering)
Of a metal, especially fuel, covered with a thin layer (*cladding*) of another metal, usually to prevent escape of fission products and to prevent corrosion.

cladding (metallurgy)
A process of coating one metal with another, which usually consists of bringing the carefully prepared surfaces of the two metals in contact, and rolling, extruding, drawing or swaging the composite until a bond is produced.

classical scattering cross section
(See Thomson scattering)

clearing field (instrumentation)
An electrostatic field applied across the gas space in a cloud chamber for clearing the chamber of ions formed at times other than the desired sensitive time.

clipper
(See clipping circuit)

clipping circuit (instrumentation)
A term with three possible meanings:

1. A circuit for preventing the peak amplitude of an electrical signal from exceeding a predetermined level.
2. A circuit for eliminating the tail of an electrical pulse after a predetermined time.
3. A circuit element in a pulse amplifier for reducing the amplification at frequencies below a predetermined frequency.

clipping time
The time constant of the clipping circuit. *(See clipping circuit (2) and (3))*

closed cycle
Cycle of operation of a heat engine in which the same power fluid is used repeatedly, as a steam engine that condenses the steam for reuse, instead of being used once and then discarded, as in a rocket or jet motor. Also applicable to a cooling system in which the coolant is cycled repeatedly through the source of heat, itself being cooled in another part of the cycle. *Cf. open cycle.*

cloud chamber, expansion chamber (instrumentation)
A device for observing the paths of ionizing particles, based on the principle that supersaturated vapor condenses more readily on ions than on neutral molecules.

cloud chamber, high-pressure
A cloud chamber in which the gas is maintained at high pressure to reduce the range of high energy particles and so to increase the probability of observing events.

Clusius column (isotopes separation)
Two versions of this apparatus exist: in one the inner hot wall is an electrically heated wire; in the other it is a cylinder of diameter comparable to that of the outer cylinder. In the separation of liquids the annular space is only a small fraction of a centimeter wide, while in the separation of gases the space is of the order of a centimeter. *(See separation of isotopes by thermal diffusion)*

coating (reactor engineering)
Integral protective envelope deposited on a fuel rod by plating, dipping, etc., and serving the same purposes as a jacket. *(See jacket)*

cocurrent flow
(See parallel flow)

coffin (reactor engineering)
A box of heavy shielding material, usually lead, used for transporting radioactive objects and having walls thick enough to attenuate radiation from the objects within it to an allowable level. Also called **casket.**

coherent scattering
(*See scattering*)

coincidence (instrumentation)
The occurrence of counts in two or more detectors simultaneously or within an assignable time interval. A **true coincidence** is one that is due to the incidence of a single particle or of several genetically related particles. An **accidental, chance,** or **random coincidence** is one that is due to the fortuitous occurrence of unrelated counts in the separate detectors. An **anticoincidence** is the occurrence of a count in a specified detector unaccompanied simultaneously or within an assignable time interval by a count in one or more other specified detectors. A **delayed coincidence** is the occurrence of a count in one detector at a short, but measurable, time later than a count in another detector, the two counts being due to a genetically related occurrence such as successive events in the same nucleus.

coincidence circuit
An electronic circuit that produces a usable output pulse only when each of two or more input circuits receive pulses simultaneously or within an assignable time interval.

coincidence counting (instrumentation)
An experimental technique in which particular types of events are distinguished from background events by means of coincidence circuits so designed or employed as to register coincidences caused by the type of events under consideration.

coincidence loss, coincidence correction
(See dead time correction)

cold area
An area in a plant or laboratory in which there is little or no contact with radioactive chemicals or radiations.

cold cathode
An electrode used to furnish electrons by secondary emission, sometimes used in the ion source of a mass spectrometer.

cold, clean reactor
A reactor having no induced radioactivity and no poisons other than those present as it was constructed. Practically speaking, this means a reactor in which a chain reaction of any appreciable power never has been established.

cold pressing (metallurgy)
The process of compressing metal or other powders in a die at room temperature to form a compact. Cold pressing is usually followed by sintering at elevated temperatures.

cold shut (metallurgy)
A discontinuity on or near the surface of a casting which results from the failure of two streams of metal to unite. Cold shuts are usually produced when the pouring temperature is too low.

collateral chain, collateral family
(See radioactive series)

collateral series
A radioactive decay series, initiated by transmutation, which eventually joins into one of the four radioactive decay series, e.g., Am^{242} and its immediate decay products in relation to the uranium decay series.

collimator (instrumentation)
A device for confining the elements of a beam within an assigned solid angle.

collision
A close approach of two or more objects (particles, photons, atomic or nuclear systems) during which there occurs an interchange of quantities such as energy, momentum, and charge. In an **elastic collision** physical content of each colliding system and kinetic energy of their centers-of-gravity motion are left unchanged, although the direction of their relative motion will probably be altered. In an **inelastic collision** at least one system gains internal excitation energy at the expense of the total kinetic energy of their center-of-gravity motion.

collision density
The number of neutron collisions with matter per unit volume per unit time. Partial collision densities may be defined for neutrons characterized by such parameters as speed and direction.

columnar ionization
(See ionization, columnar)

compact
A briquette produced by the compression of metallic or non-metallic powders in a die.

comparative lifetime
The product ft of the half-life t of a beta disintegrator and a function f that expresses the probability per unit time that a beta transition will take place in a given nucleus. The value of f is determined primarily by the beta disintegration energy, but it also depends upon the atomic number of the product nucleus because of the influence of the nuclear Coulomb field upon the beta particle. The use of ft products puts all beta disintegrators on a common basis so far as the disintegration energies and the atomic numbers are concerned, with the result that the comparative lifetimes are measures of the inherent forbiddenness of the beta transitions. With t conventionally expressed in seconds, the values of $\log_{10} ft$ vary from 2.7 for the most highly allowed transition known (He^6) to 22 for the most forbidden transition known (In^{115}). In cases of *branching*, the appropriate partial half-life and the disintegration energy for the branch in question must be used for the evaluation of t and f, respectively.

compensating coils
A set of coils so distributed as to alter a magnetic flux distribution in a desired manner.

compound nucleus
(See nucleus)

compressible flow
The flow of fluid under conditions such that its density changes significantly.

compressibility factor
The ratio of the actual volume of a given mass of gas to the volume which it would have at the same temperature and pressure if it were a perfect gas.

Compton absorption
The absorption of an x-ray or gamma ray photon in the *Compton effect*. The energy of the electromagnetic radiation is not completely absorbed since another photon of lower energy is simultaneously created.

Compton effect
The elastic scattering of photons by electrons. Since the total energy and total momentum are conserved in the collisions, the wavelength of the scattered radiation is changed by an amount that depends on the angle of scattering θ. If the scattering electron is assumed to be initially at rest, the **Compton shift** is given by the equation $\lambda' - \lambda = \lambda_o (1 - \cos\theta) = \frac{h}{m_e c}(1 - \cos\theta)$, where λ' and λ are the wavelengths associated with the scattered and incident photons, θ is the angle between their paths, and λ_o [$\equiv h/m_e c$] is the *Compton wavelength* of the electron.

Compton recoil electron
An electron that has been set in motion through interaction with a photon in the *Compton effect.*

Compton recoil particle
Any particle that has acquired its momentum in a scattering process similar in type to the *Compton effect.*

Compton wavelength
A wavelength λ_o characteristic of a particle of mass m_o and equal to $h/m_o c$. For example, its values for the electron and the proton are 2.43×10^{-10} and 1.32×10^{-13} cm, respectively. The *Compton shift* for Compton-type scattering through a given angle is proportional to the Compton wavelength of the particle but is independent of the wavelength of the photon. The Compton wavelength should not be confused with the *de Broglie wavelength. (See de Broglie relation)*

concrete (reactor engineering)
A stone-like substance made of Portland cement, sand, and solid material such as crushed stone or gravel (the aggregate) mixed with water, which causes the cement to set and bind the whole. Concrete is important as a structural and also as a shielding material. It is much used in the latter connection because of its convenience, availability, and low cost compared with alternative substances and because in many cases a shield may be a structural wall as well. Its density (up to about 150 pounds per cubic foot for reinforced concrete) contributes to its shielding effectiveness; and its high hydrogen content (largely from water added to set the cement) is helpful in slowing down neutrons. To increase the density of concrete so that a shield may be more compact, the aggregate and sometimes the sand may be replaced by denser material, such as iron ore or steel scrap or shot or a combination of these materials, the resulting material being known as **heavy-aggregate concrete.**

concurrent centrifuge
The application to isotope separation of the centrifugal cream separator. One or more streams of gas enter at one end of the centrifuge and the partially separated isotopes are removed in two or more streams at the other end.

condensation
The formation of a liquid or solid from a vapor.

condenser r-meter, condenser ionization chamber (biophysics)
Ionization instrument for measuring x- or gamma rays, consisting of an electrometer and a detachable ionization chamber, embodying a condenser of suitable capacitance. This can be attached to the electrometer and the entire system charged. It is then detached from the electrometer, exposed to the radiation and thereby partly discharged, and returned to the electrometer for reading the decrease in charge. The instrument can be calibrated to read directly in

roentgens at the position of the center of the chamber, over a considerable range of photon energies, provided the ionization chamber is suitably constructed. *(See ionization chamber)*

conduction
The flow of heat through a body by the transfer of kinetic energy from molecule to molecule without gross mixing.

configuration control
Control of the reaction rate of a nuclear reactor by change in the configuration of its core. An example is *mass separation.*

conjugate layers (chemical engineering)
In solvent extraction, the two immiscible solutions in equilibrium with each other.

constant-potential accelerator
A device in which a d-c potential is applied to an accelerating tube to produce high-energy ions or electrons.

constant rate drying period
In the drying of solids, a period in the initial stages of drying in which the rate of moisture loss is essentially constant.

constitution diagram
(See phase diagram)

contact radiation therapy
X-ray therapy with specially constructed tubes in which the target-skin distance is very short (less than 2 cm). The voltage is usually between 40 and 60 kv.

contaminated
Made radioactive by the addition of (sometimes) minute quantities of radioactive material.

contamination, radioactive
1. A condition in which an undesirable radioactive substance is mixed with a desired substance.
2. A condition in which radioactive material has spread to places where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for some specific use.

(Reactor engineering) Radioactive material on the walls of vessels in used-fuel reprocessing plants; radioactive material that has leaked into a reactor coolant.

continuity equation
Any equation relating the rate of inflow of a quantity into a volume to the rate of increase of the amount of the quantity within the volume.

continuous process
A process in which for extended periods uninterrupted flows of proportioned components enter and products leave a system.

continuous spectrum, continuous x-rays, continuous x-radiation
(See spectrum)

control
The purposeful variation of the reactivity of a reactor. **Absorber control** is obtained by variation of the amount of neutron absorbers within the reactor. **Configuration control** is obtained by changing the geometry of the reactor. (*See absorption control*; *moderator control*; *control element*; *control rod*; *control system*; *start-up procedure*)

control element
The element of a control system through which the system's regulating effect is applied to a process. In a nuclear reactor, commonly a control rod or equivalent device. *(See control rod)*

control rod
Any rod used to control the reaction rate in a nuclear reactor, which it does by changing the effective multiplication constant and hence the reaction rate's time derivative. It may be a fuel rod or a part of the moderator; in thermal reactors it commonly is a neutron absorber. Cadmium and boron (in the form of boron steel) are suitable absorbing materials. Sometimes absorbing control rods are made of fertile material to utilize the neutrons absorbed in control. The term includes *power control rod, regulating rod, safety rod, shim rod.*

control system
(Reactor engineering) A system of apparatus for controlling the rate of reaction in a nuclear reactor. The term may refer to all apparatus provided for this purpose or to one of several essentially independent arrangements, such as a regulating system and a safety system. A reaction may be controlled automatically by a servo system that adjusts the control elements as necessary to hold the flux level close to a desired value. A reactor may have a tendency toward stability because of self-regulation, but the quality of stability ordinarily is not considered part of the control system. *(See automatic control system)*

convection
The transfer of heat or mass by circulation or mixing.

conversion, internal
The emission of an electron in the de-excitation of a nucleus by direct coupling between the excited nucleus and an extranuclear electron, usually one in the *K, L* or *M* shell. The ejected electron, called a **conversion electron,** has kinetic energy which is the difference between the transition energy and the binding energy of that electron. Conversion electrons are observed in a beta-ray spectrometer as a line spectrum easily distinguishable from the continuous *beta-ray spectrum* when beta rays are present. The direct emission of the excitation energy in the form of a gamma-ray photon is a competing process. Internal conversion is followed by emission of characteristic x-rays or Auger electrons as a consequence of the necessary rearrangement of the atomic electrons. The ratio α of the probability of an internal conversion transition to the probability of a radiative transition between the same two states is called the **internal conversion coefficient.** There are separate internal conversion coefficients for the ejection of electrons from the *K, L,* . . . shells. The total internal conversion coefficient is the sum of the *K, L,* . . . conversion coefficients. In some older literature the internal conversion coefficient referred to the probability that a conversion electron rather than a gamma-ray photon will be emitted; in this usage it has a maximum value of unity.

conversion coefficient, conversion electron
(See conversion ratio; conversion fraction; conversion, internal)

conversion fraction
The ratio of the number of internal conversion electrons to the total number of quanta plus the number of conversion electrons emitted in a given mode of de-excitation of a nucleus. Partial conversion fractions refer to conversion fractions for various electron shells, e.g., K-conversion fractions, L-conversion fractions, etc. Sometimes called conversion coefficient. *(See conversion, internal)*

conversion gain (reactor theory)
Conversion ratio minus one.

conversion ratio
The ratio of the number of internal conversion electrons to the number of gamma quanta emitted in the de-excitation of a nucleus. Also called **conversion coefficient.** Partial conversion ratios refer to conversion ratios for the various electron shells, e.g., K-conversion ratio, L-conversion ratio, etc. (Reactor theory) In a converter, the number of fissionable atoms produced per fissionable atom destroyed.

converter
A nuclear reactor that converts fertile atoms into fuel by neutron capture. Two different ways of using the words converter and breeder are in use at present:

1. A **converter** is a reactor that uses one kind of fuel and produces another (e.g., consumes U^{235} and produces Pu from U^{238}) and a **breeder** produces the same kind of fuel (e.g., consumes Pu and produces more Pu from U^{238}).
2. A **breeder** is a converter that produces more fissionable atoms than it consumes.

coolant
A substance, either a gas or a fluid, used for cooling any part of a reactor in which heat is generated. Such parts include not only the core but also the reflector, shield, and other elements that may be heated by absorption of radiation.

cooling

1. A colloquial term used to describe the reduction in radioactivity of some material by radioactive decay.
2. A colloquial term used for the setting aside of a highly radioactive material until the radioactivity has diminished to a desired level.

coprecipitation (chemistry)

1. The carrying of trace amounts of (active) material on a ponderable precipitate of another composition. It may involve trace ion replacement in the crystal lattice of the carrier when the two substances are truly isomorphous; it may involve the formation of anomalous mixed crystals; it may involve adsorption at the time of formation or later of the trace ion on the highly charged surface of the carrier precipitate; or it may involve the internal adsorption of the trace in aggregate spots within the carrier precipitate.
2. The precipitation of a substance from concentrations below its solubility when induced by the precipitation of another substance.

core
In a nuclear reactor, the region containing the fissionable material.
The body of fuel or moderator and fuel in a nuclear reactor. It does not include the fuel outside the active section in a circulating reactor. Identical with active lattices in a reactor. (*See active lattice*; *lattice*)
In a heterogeneous reactor, the region containing fuel-bearing cells.

core circuit
(See thermal cycle)

coring (metallurgy)
A variation in composition within the dendrites or grains of a cast solid solution phase caused by failure to achieve equilibrium during solidification. The alloy which solidifies initially contains a greater proportion of the component which raises the freezing temperature of the liquid, and the interior (core) of the dendrite is thereby enriched in this component.

coseparation
(*See coprecipitation*)

cosmic abundance
The quantity of a nuclide or element in the universe relative to that of some standard species, often the element silicon.

cosmic ray shower
The simultaneous appearance of several or many light ionizing particles with or without accompanying photons, the particles being directed predominantly downward and having a common ultimate origin in an event caused by a single cosmic ray. Showers reveal themselves by the simultaneous actuation of separated counters and (sometimes spectacularly) in cloud chambers. They can be roughly classified according to their properties as **narrow showers, extensive** (or **Auger**) **showers, penetrating showers,** and **cascade showers.**

cosmic rays
Radiation that has its ultimate origin outside of the earth's atmosphere, that is capable of producing ionizing events in passing through the air or other matter, and that includes constituents capable of penetrating many feet of material such as rock. The **primary cosmic rays** probably consist of atomic nuclei, mainly protons, some of which may have energies of the order of 10^{10} to 10^{15} ev. **Secondary cosmic rays** are produced when the primary rays interact with nuclei and electrons, for example, in the earth's atmosphere; they consist mainly of mesons, protons, neutrons, electrons and photons that have less energy than the primary rays. Practically all of the primary cosmic rays are absorbed in the upper atmosphere, and almost all cosmic radiation observed at the earth's surface is of the secondary type.

cosmotron
(See proton-synchrotron)

Coulomb force (electrostatics)
The electrostatic force F of attraction or repulsion exerted by one particle of charge q_1 on another particle of charge q_2. For a vacuum it is given by the Coulomb electrostatic equation, $F = k\, q_1 q_2/r^2$ where k is a proportionality factor that depends only on the units employed, and r is the distance between the two particles. The electrostatic force F of the one particle on the other is attractive or repulsive, depending on whether q_1 and q_2 have unlike or like signs.

Coulomb potential
In the field of a particle of charge q in a vacuum, a scalar point function V, equal to the work per unit charge done against or by the *Coulomb force*, in the transfer of a positive test charge (a particle bearing an infinitesimal charge) along any path from infinity to the field point in question. For a point charge it is given by $V = k\, q/r$, where k is a proportionality factor that depends only on the units used, and r is the distance of the field point from the charge q. The potential V is positive or negative, according to whether work must be done to bring the positive test charge from infinity or to take it to infinity from the field point. The potential due to a number of charged particles is the scalar algebraic sum of the potentials due to the individual particles.

count (radiation measurements)
The external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term is loosely used to designate a disintegration, ionizing event or voltage pulse.

counter
A device for counting ionizing events. The term may refer to a

complete instrument or loosely to the detector.

counter-controlled cloud chamber
A cloud chamber whose expansion is triggered by a counter or counters, used for studying particular events.

counter-current centrifuge (isotope separation)
In this device counter-current circulation is established in a centrifuge either thermally or mechanically. By the circulation of the gas the radial concentration gradient is converted into an axial gradient.

counter-current flow
The flow in opposite directions of two streams within a system.

counter range
A low range of the reaction rate in a reactor, in which neutron flux cannot be measured by the permanently installed control instruments but must be measured by counters. It is found in the start-up procedure. *(See instrument range; power range; neutron source)*

counterflow
An alternative term for counter-current flow.

counting ionization chamber
(See pulse ionization chamber)

counting loss
(See dead time correction)

counting rate
The average rate of occurrence of ionizing events as observed by means of a counting system.

counting-rate meter
A device which gives a continuous indication of the average rate of ionizing events.

counting rate-voltage characteristic
(See plateau characteristic)

counts, background

1. Counts caused by any agency other than the one which it is desired to detect.
2. Counts caused by radiation coming from sources external to the counter tube other than the source being measured, or by radioactive contamination of the counter tube itself. (I R E Definition.)

coupling
An interaction between different properties of a system, or an interaction between two or more systems. Examples in atomic and nuclear physics are: the interaction between intrinsic and orbital angular momentum of a particle, called **spin-orbit coupling**; the interaction between two or more particles, each of which exhibits spin-orbit coupling, called **j-j coupling**; the interaction between the resultant orbital angular momentum of two or more particles and their resultant intrinsic angular momentum, called **Russell-Saunders** (or **L-S**) **coupling**; the interaction between the *lepton* field and a *nucleon* involved in a *beta disintegration* process.

coupling constant
A constant expressing the strength of a particular *coupling*. In a field theory, the total energy operator can be written as $H = H_0 + H^1$, where H_0 represents the energy of the matter plus the energy of the radiation (the term radiation is here used in its general sense and covers, for example, the electron-neutrino field in the case of beta-decay), and H^1 represents the interaction energy. A standard procedure consists in assuming that H^1 is proportional to a matrix element, or a component thereof, M, of simple form: $H^1 = gM$. The numerical factor g is called the **coupling constant.** *Transition probabilities* are proportional to g^2 as well as to M^2. *(See Fermi constant)*

creep
The plastic deformation of metals that occurs with time upon application of load. Under constant load, the rate of deformation is large at the outset (**initial** or **primary creep**), and later becomes substantially constant (**second stage** or **secondary creep**). Eventually the metal may deform rapidly once more and may ultimately rupture (**third stage** or **tertiary creep**). The slope of the elongation-time curve during the second state is usually called the **creep rate.**

crit (reactor theory)
The mass of fissionable material which, under a given set of conditions, is critical. Sometimes applied to the mass of an untamped critical sphere of fissionable material.

critical (reactor theory)
Capable of sustaining (at a constant level) a chain reaction. **Prompt-critical** is capable of sustaining a chain reaction without the aid of delayed neutrons. *(See delayed-critical)*

critical equation
Any equation relating parameters of a reactor which must be satisfied for the reactor to be critical.

critical experiment (reactor engineering)
Experiment in which fissionable material is assembled gradually until the arrangement will support a self-sustaining chain reaction; its purpose is to determine the critical size and operating and control features of a proposed reactor or of a new reactor prior to operation. It is carried out at substantially zero power so that forced cooling is unnecessary and fission-product activity is negligible. Such quantities as critical mass, temperature coefficient of reactivity and control rod effectiveness are often measured. *Cf. zero-power reactor.*

critical mass
The mass of fissionable material in a critical reactor.

critical moisture content (chemical engineering)
In the drying cf solids, the moisture content at the end of the constant rate drying period and the beginning of the falling rate period.

critical shear stress (metallurgy)
The resolved shear stress which is required to initiate slip in a given crystallographic direction along a given crystallographic plane of a single crystal of a metal.

critical size (reactor theory)
Any one of a set of physical dimensions of the core and reflector of a nuclear reactor maintaining a critical chain reaction, the material and structure of the core and the reflector having been specified.

critical velocity (chemical engineering)
That average linear velocity below which a given fluid, at a given temperature and pressure, flowing in a given apparatus, will move in streamline flow and above which the motion is usually turbulent.

cross bombardments
A method for the mass assignment of a radioactive species based on its production by several nuclear bombardments using different projectiles and/or different target materials.

cross section, σ (reactor theory)
For a given event, the probability per unit flux and per unit time, that the event will occur. The cross section per atom of medium has the dimensions of an area, whereas the cross section per unit volume of medium is a reciprocal length. For a particular nuclear reaction, σ may be

greater or smaller than the geometric cross section πR^2. If the reaction cannot take place, the cross section is zero. For any collision reaction between nuclear or atomic particles or systems, σ is an area such that the number of reactions taking place is equal to the product of the number of incident particles which would pass through this area at normal incidence and the number of target particles or systems. If n_t is the number of target nuclei or other particles per unit area of a substance exposed to an incident beam consisting of n_0 particles, then $\sigma = N/n_0 n_t$, where N is the number of reactions of a specified type. Typical cross sections commonly encountered for nuclei are: cross section for slow neutron capture, cross section for fission, cross section for $(d, 2n)$ reaction, and cross section for elastic scattering. Typical of those for atoms are cross section for Compton collision and cross section for ionization by electron impact. The cross section for a given reaction depends on the energy of the incident particles or photons. The **total cross section** σ_s is that cross section effective for removal of an incident particle from a beam; it is the sum of the separate cross sections for all processes by which the particle can be removed from the beam. For an absorber all of whose atoms have the same total cross section, the latter is the same as the atomic *absorption coefficient*. In an ideal beam transmission experiment, the attenuation factor will be $e^{+nx\sigma}$, where n is the number of atoms per unit volume, and x is the distance traversed. The total cross section of an atom for a nuclear particle is essentially the sum of the absorption and scattering cross sections; for a photon it is essentially the sum of the Compton scattering, photoelectric and pair production cross sections. *(See beam)*

cross section kT, σ_{kT} (reactor theory)
A term used in literature to denote $2/\sqrt{\pi}$ multiplied by the thermal cross section measured with neutrons of "temperature" T. If the thermal neutrons have a maxwellian distribution and the cross section varies as $1/v$, then σ_{kT} is the cross section for monoenergetic neutrons of energy kT.

cross section, activation
The *cross section* for the formation of a specified radionuclide. It is used most frequently for neutron-induced reactions.

cross section, capture
The *cross section* effective for radiative capture. *(See capture, radiative)*

cross section, differential
The *cross section* for a nuclear process leading to emission of particles or photons at a specified angle relative to the direction of incidence, per unit angle or per unit solid angle; an example is the cross section for scattering of neutrons at an angle of 40°. The differential cross section may be expressed in terms of either unit plane angle or unit solid angle. Integration over all angles from 0° to 180° gives the ordinary cross section for the process. *(See differential scattering cross section)*

cross section, macroscopic
The combined cross section Σ for a specified process for all atoms per unit mass of a material, such as an element, compound or mixture. For a mixture, $\Sigma = \sigma_1 n_1 + \sigma_2 n_2 + \ldots + \sigma_i n_i + \ldots$, where σ_i is the cross section for atom of type i and μ_i is the number of such atoms per unit mass.

cross section, stopping
A synonym for atomic stopping power. *(See stopping power)*

crossing over (biophysics)
The mutual exchange, during prophase of meiosis, of corresponding segments of homologous chromatids.

crud (chemical engineering)
A slang term referring to an undesirable impurity or foreign material arising in a process.

crystal counter (instrumentation)
A counter utilizing one of several known crystals which are rendered momentarily conducting by ionizing events.

crystal effects (reactor theory)
Dependence of the macroscopic neutron cross section of a material upon the crystalline structure of the material.

crystal or Bragg spectrometer
An instrument for measuring x-ray or gamma ray wavelength by means of diffraction by a crystal.

curie, c
1. The present definition of the curie is: The unit of radioactivity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.70×10^{10}.
2. An earlier definition of the curie was: The quantity (grams) of radon in equilibrium with one gram of radium.

curium (Cm)
An element, atomic number 96, discovered in 1944 by G. T. Seaborg, R. A. James and A. Ghiorso. They synthesized 150*d* Cm^{242} by helium ion bombardment of Pu^{239}. Other isotopes have been characterized. The element was named for Pierre and Marie Curie. The only known oxidation state is +3.

current density (reactor theory)
A vector such that its component along the normal to a surface equals the net number of particles crossing that surface per unit area and unit time. Commonly referred to simply as current; as in neutron current.

curtain (reactor engineering)
A thin shield, usually cadmium, interposed to shut off a flow of slow neutrons.

cut (chemical engineering)
1. A defined fraction of the stream leaving a separations process.
2. To dilute.
3. (Isotopes separation) The fraction of the feed into a separative element which is removed as product or advanced to the next separative element in the direction of the product.

cyclotron
A device for accelerating charged particles to high energies by giving successive increments of energy from an alternating electric field between electrodes placed in a constant magnetic field. *(See synchrocyclotron)*

cytoplasm (biophysics)
The protoplasm of a cell, exclusive of the nucleus.

cytoplasmic inheritance (biophysics)
Inheritance which is not controlled by the genes in the nucleus, but by the cytoplasm. *(See plasmagene)*

D

D, d
Symbol for deuterium. (*See deuteron; hydrogen)*

"D" neutrons (reactor theory)
Neutrons of such energy that they are strongly absorbable by rhodium covered with cadmium. This term is now obsolete.

danger coefficient (reactor theory)

1. The danger coefficient of a substance for a particular reactor is the change in reactivity caused by inserting that substance in the reactor. The danger coefficient depends on the amount and distribution of the substance inserted, usually quoted as reactivity change per unit mass for a standard position in the reactor.
2. A number expressing relative poisoning effects of different materials. From this coefficient one can estimate the loss in reactivity that would be incurred by having these materials in the reactor.

daughter
A nuclide formed in the radioactive decay of another (called the *parent*). A synonym for *decay product.*

dead time (instrumentation)
An interval after response to one signal or event during which a system is unable to respond to another. The time interval, after a count, during which a radiation detector and/or its circuit are insensitive to ionizing events.

dead time correction
Correction to the observed counting rate to allow for the probability of the occurrence of events within the dead time.

de Broglie relation
The expression $\lambda = h/p$ for the **de Broglie wavelength** λ ascribed by wave or quantum mechanics to any particle having momentum p. For a relativistic particle of rest mass m_o and velocity v,

$$\lambda = \frac{h}{m_o v} \sqrt{\frac{1-v^2}{c^2}}$$

decade scaler
(See scaler)

decay, radioactive
The spontaneous transformation with a measurable life-time of a nuclide into one or more different nuclides. The process involves the emission from the nucleus of alpha particles, electrons, positrons, gamma rays, or the nuclear capture or ejection of orbital electrons, or fission. A synonym for radioactive disintegration. *(See radioactivity)*

decay chain, family, or series
A series of radioactive nuclides in a decay sequence such that each forms the next one by decay. Such a series continues until a stable nuclide is formed. Decay chains are common among the heaviest elements and among the fission products. (*See radioactive series*)

decay constant, λ
The constant characteristic of a radionuclide in the equation

$$-\frac{dN}{dt} = \lambda N$$

relating the instantaneous rate of decay,

$$-\frac{dN}{dt}$$

of a radioactive species to the number of atoms, N, present at a given time. If N_0 is the number of atoms present at time zero, then

$$N = N_0 e^{-\lambda t}$$

In case of *branching* decay, the decay constant is the sum of partial decay constants characteristic of the various modes of decay. *(See disintegration constant)*

decay curve
A plot of the activity of a sample or some function of the activity (such as the logarithm of the counts/unit of time) vs time. A curve showing the relative amount of radioactive substance remaining after any time interval. **simple decay curve** For a single radioactive substance, the plot of the equation $N_t = N_0 e^{-\lambda t}$, where N_0 is the amount present at time zero, and λ is the disintegration constant. **compound decay curve** For a sample containing several radioactive substances, the sum of the simple decay curves for the individual substances.

decay law, radioactive
The exponential law

$$N = N_0 e^{-\lambda t}$$

which governs the decrease with time of the number of atoms of a radioactive species, provided the number is large. In the above equation, N is the number of atoms present at time t, N_0 is the number of atoms present at time zero and λ is the decay constant. The decay law is a statistical law so that if N is the number of radioactive atoms present, the number which will disintegrate on the average in unit time is λN. The number which will disintegrate in any particular unit of time may not be exactly λN but if a large number of measurements of the number of disintegrations per unit time is made, the values will show a Poisson distribution with λN as the average value.

decay product
A nuclide resulting from the radioactive disintegration of a radionuclide, being formed either directly or as the result of successive transformations in a *radioactive series*. A decay product may be either radioactive or stable.

decontamination
1. The removal of unwanted radioactive substances from a desired material, e.g., removal of fission products from plutonium or uranium.
2. The removal of undesired dispersed radioactive material from personnel, instruments, rooms, equipment, etc. In the case of physical objects this may involve thorough washing, often with chemical solutions; and in the case of fluids such as air, it may involve filtering and washing. (*See contamination, radioactive*)

decontamination factor
The absolute ratio of initial specific radioactivity to final specific radioactivity resulting from a separation process. Decontamination factors may refer to the removal of some particular type of radiation, or of a gross measurable radioactivity. Sometimes the *decontamination index* is meant.

decontamination index
The logarithm of the ratio of initial specific radioactivity to final specific radioactivity resulting from a separation process.

dee (instrumentation)
A hollow accelerating electrode in a cyclotron.

dee lines
Structural members which support the dees of a cyclotron. Together with the dees they comprise the resonant circuit.

deflector
A device which applies electrostatic and/or magnetic forces to cause accelerated particles to depart from their normal path.

deformation bands (metallurgy)
Regions within a metal crystal which have assumed different orientations as a result of slip.

degradation
Loss of energy by collision. Neutron degradation is also called *moderation.*

delay (reactor engineering)
Time between the establishment of an undesired condition (e.g., excess power or short period) and the start of corrective motion of a control rod.

delayed alpha particles
Alpha particles emitted promptly by excited nuclei formed in a *beta disintegration* process. Alpha particle emission must occur so rapidly that it competes successfully with deexcitation by gamma emission. The half-life observed for the alpha particles is that of the beta emitter. The situation is similar to that for *delayed neutrons*. An example of a **delayed alpha emitter** is N^{12}, positron disintegration of which leads part of the time to an excited state of C^{12} whose excitation energy exceeds its alpha particle binding energy; the observed half-life in this case is 0.013 sec. The long-range alpha particles are additional examples of delayed alpha particles. (*See spectrum; binding energy,* ***alpha*** *particle*)

delayed coincidence
(See coincidence)

delayed-critical (reactor engineering)
The condition of a nuclear reactor that is critical (effective multiplication constant = 1) because of both prompt and delayed neutrons. The term **critical** often is used alone to mean **delayed-critical**. (*See delayed neutrons; prompt-critical*)

delayed neutrons
Neutrons emitted by excited nuclei formed in a radioactive process (*beta disintegration*, in all cases so far known), so called because emitted an appreciable time after the fission. The neutron emission itself is prompt, so that the observed half-life is that of the preceding beta emitter. The situation is similar to that involving gamma-ray emission, which is a competing process. Delayed neutron emission is possible only if the excitation energy of the product nucleus exceeds the neutron binding energy for that nucleus. The chemistry of the **delayed neutron emitter** is that of the beta activity; thus Br^{87}, I^{137} and N^{17} are delayed neutron emitters, although the neutron emission actually takes place from excited nuclei of the products Kr^{87}, Xe^{137} and O^{17}, leading in these cases to stable Kr^{86}, Xe^{136} and O^{16}, respectively. At least five delayed neutron activities with half-lives of 0.4 to 55 sec occur in the fission products; they are important in the control of nuclear chain reactions, for they afford a time-margin of safety following small reactivity changes dur-

ing which control or safety rods can be set in motion. The delayed neutrons from the fission of U^{235} have been determined as follows:

Mean Life	% of Fission Neutrons, β_i	Identification of Delayed Emitter
55.6 sec.	0.026	Kr^{87}
22.0	0.17	Xe^{137}
4.51	0.21	
1.52	0.24	
.43	0.084	
.05	0.029	

Total $\beta = 0.76\%$
(See fission neutrons; uranium)

deletion, chromosome
(See chromosome deletion)

delta ray

1. An electron ejected by recoil when a rapidly moving alpha particle or other charged particle passes through matter. In a Wilson cloud chamber it may produce a short, faint track that branches from the track of the primary particle.
2. By extension, any secondary ionizing particle, such as a proton, that is ejected by recoil when a primary ionizing particle passes through matter.

denaturant
A non-fissionable isotope which can be added to fissionable material to make it unsuitable for use in atomic weapons without extensive processing. An example of a denaturant would be U^{238} which, when added in sufficient quantity to U^{235} or U^{233}, would render these unsuitable for weapon use.

dendrite (metallurgy)
A crystal, usually produced by solidification of liquid, and characterized by a treelike structure with many branches.

densitometer
Instrument for measuring photographic density.

density (photographic)
The degree of darkening of photographic film; expressed as the logarithm of the opacity of exposed and processed film. Opacity is the reciprocal of transmission; transmission is the ratio of transmitted to incident intensity.

dephlegmation (chemical engineering)
The partial condensation of a mixed vapor, thereby increasing the concentration of the more volatile constituents in the remaining vapor.

depleted material
Material in which the amount of one or more isotopes of a constituent has been reduced by an isotope separation process or by a nuclear reaction (e.g., uranium depleted in U^{235}).

depletion
Percentage reduction in the quantity of fissionable atoms in the fuel assemblies or fuel mixture of a nuclear reactor by their consumption in the course of reactor operation, e.g., reduction in the U^{235} content of natural uranium.

depth dose
(See dose, depth)

desorption
The reverse process of adsorption whereby adsorbed matter is removed from the adsorbent. The term is also used as the reverse process of absorption.

detector, radiation (instrumentation)
Any device for converting radiant energy to a form more suitable for observation. (Reactor engineering) An instrument used to determine the presence and sometimes the amount of radiation or neutron flux.

deuterium, D, d
The hydrogen isotope of mass number 2. It is found in natural hydrogen to the extent of 1 atom in 6500 ± 100. Its mass is 2.01471 ± .00007 amu. The symbol D is often used to designate deuterium in compounds, as HDO for molecules of that composition. Official chemical nomenclature uses the designation *d* with a number which designates the carbon atom to which the deuterium is bound; e.g., $2-d$ propane designates CH_3CHDCH_3. *(See hydrogen)*

deuteron
The nucleus of a deuterium, or heavy hydrogen, atom ($Z = 1$, $A = 2$), the hydrogen isotope of mass number 2. It consists of a neutron and a proton. The symbol, *d*, is used for the deuteron as a projectile.

difference number
A synonym for *neutron excess.*

differential absorption ratio (radiobiology)
Ratio of concentration of an isotope in a given organ or tissue to the concentration that would be obtained if the same administered quantity of this isotope were uniformly distributed throughout the body.

differential ionization chamber (instrumentation)
A two-section ionization chamber with the electrode potentials so arranged and controlled that the output current is equal to the difference between the separate ionization currents of the two sections.

differential scattering cross section
Cross section for scattering of a particle from its initial velocity to a new velocity, per unit solid angle per unit speed at the new velocity. *(See cross section, differential)*

diffraction instrument
Any device employed for studying the structure of matter or the properties of radiation by means of the diffraction of waves; for example, x-rays, electrons, or neutrons.

diffusion (chemical engineering)
Flow relative to each other of the constituents of a single phase mixture; such relative flow may occur when the different parts of the mixture are in disequilibrium: e.g., **thermal diffusion** results from nonuniformity of temperature, **pressure diffusion** from that of pressure; **ordinary diffusion**, from that of composition. In **eddy diffusion** the mechanism is mixing by turbulence; in **molecular diffusion**, mixing by thermal agitation of the molecules alone. (Reactor theory) The passage of particles through matter in such circumstances that the probability of scattering is large compared with that of leakage or absorption. It is often limited to phenomena described by a member of the class of differential equations known as diffusion equations.

diffusion, molecular (isotopes separation)
A process whereby one substance gradually interpenetrates another substance as a result of the continuous thermal motion of the individual molecules. Diffusion due to molecular motion satisfies a partial differential equation of the form

$$\frac{\partial \rho}{\partial t} = D \frac{\partial^2 \rho}{\partial x^2}$$

where ρ is the density of the diffusing material, t is the time and x is distance in the direction of the density gradient. The quantity D is known as the **coefficient of diffusion** for the mixture in question; it turns out to be rate-determining in all separation processes using gases or liquids at pressures where molecular collisions are a significant phenomenon.

diffusion barrier (isotopes separation)
A porous partition, such as an unglazed clay plate, which restricts ordinary hydrodynamic flow, and through which material transfer takes place principally by diffusion.

diffusion coefficient (reactor theory)
The constant of proportionality in Fick's law, which states that the current is proportional to the negative gradient of the flux or of the density. The corresponding proportionality constants are the diffusion coefficient of flux and of density.

diffusion equation, elementary
The equation obtained by using Fick's law to relate the current density to the neutron density in a continuity equation.

diffusion length
A length appearing in the description of diffusion when *Fick's law* applies. The square of the diffusion length (called the **diffusion area**) is equal to one-sixth the mean square distance traveled by a particle of a given type or class from appearance to disappearance within an infinite homogeneous medium.

diffusivity (chemical engineering)
The relative rate of flow per unit area of a particular constituent of a mixture divided by the gradient of composition, temperature or other property considered to be causing the diffusion. Also *diffusion coefficient.*

diploid (biophysics)
Having two complete sets of chromosomes, the normal somatic number of chromosomes in higher organisms, as opposed to the half number *haploid*, found in mature germ cells. cells.

Dirac h
(See h)

direct radiation
Obsolete term for all radiation other than the useful beam; now designated as **leakage radiation.** Colloquially, the term direct radiation is often used to denote *useful beam.*

disadvantage factor
The ratio of the average neutron flux in a cell to the average neutron flux within the fissionable material.

discomposition
The process in which an atom is knocked out of its position in a crystal lattice by direct nuclear impact, e.g., by fast neutrons or by fast ions which have been previously knocked out of their lattice positions. The atom so displaced may eventually come to rest at an interstitial position or at a lattice edge.

discomposition effect
Change in chemical or physical properties resultant from discomposition. Also called *Wigner effect.*

discriminator
(See pulse height discriminator)

disintegration
A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy from the nucleus. When numbers of nuclei are involved the process is characterized by a definite half-life. *(See radioactive half-life)*
(Chemistry)
1. Radioactive decay.
2. The transformation of one nuclide into one or more different nuclides by bombardment with high energy particles such as alpha particles

or helium ions, deuterons, protons, neutrons or gamma rays.

disintegration, nuclear
Any transformation or change involving nuclei. If the disintegration is spontaneous, it is said to be *radioactive;* if it results from a collision, it is said to be *induced.* Despite its literal meaning, the term nuclear disintegration refers also to radiative capture, inelastic scattering, beta transformations, and isomeric transition. (*See radioactivity*; *reaction, nuclear*)

disintegration chain, family, or series
Synonyms for *radioactive series.*

disintegration constant
The fraction of the number of atoms of a radioactive isotope which decay in unit time, shown as λ in the equation $N = N_0 e^{-\lambda t}$, where N_0 is the initial number of atoms present. The probability per unit time, λ, that a given unstable particle or system, such as a radioactive atom, will undergo spontaneous transformation. It is defined by the equation $dN/dt = -\lambda N$, where N is the number of untransformed particles or systems existing at time t. It is the reciprocal of the *mean life* of the given system before undergoing transformation. When *branching* occurs, there are **partial disintegration constants** $\lambda^1, \lambda^2, \ldots$ associated respectively with the various possible modes of disintegration; the **total disintegration constant** λ for the parent substance then is given by $\lambda_1, + \lambda_2 + \ldots.$ *(See half-life)*

disintegration energy
The energy released in radioactive decay. It may be manifest in radiant energy, heat energy or kinetic energy imparted to the product particles. This energy is distributed among the products (which may include quanta and neutrinos). In case of positron emission, the disintegration energy includes also the rest mass of a positron or electron. *(See reaction energy, nuclear)*

disintegration energy, nuclear, Q

1. The energy evolved, or the negative of the energy absorbed, in a nuclear disintegration. It is equal to the energy equivalence of the sum of the masses of the reactants minus the sum of the masses of the products. (For each reactant or product which is a nucleus, the appropriate mass is that of the corresponding neutral atom.) If the disintegration energy is positive, the disintegration is *exothermic*; if it is negative, the disintegration is *endothermic*. Radioactive disintegrations have positive Q-values; nuclear reactions may have Q-values of either sign.
2. Often, implicitly, the **ground-state disintegration energy,** which is the disintegration energy when all reactant and product nuclei are in their ground states; symbol Q_0. (*See alpha disintegration energy; beta disintegration energy; reaction energy, nuclear*)

disintegration rate

1. The absolute rate of decay of a radioactive substance usually expressed in terms of disintegrations per unit of time.
2. The absolute rate of the transformation of a nuclide under bombardment.

dislocation (metallurgy)
A type of lattice imperfection whose existence in metals is postulated in order to account for the phenomenon of crystal growth and of slip, particularly for the low value of shear

stress required to initiate slip. One section of the crystal adjacent to the slip plane is assumed to contain one more atomic plane than the section on the opposite side of the slip plane. Motion of the dislocation results in displacement of one of the crystals with respect to another.

displacement kernel
(See kernel)

displacement law
(See radioactive displacement law)

distillate
The volatile product from a distillation system.

distillation
The separation of the components of a liquid mixture by partial vaporization of the mixture and separate recovery of vapor and residue.

distillation column, distillation tower
A column or tower used in distillation. *(See also plate column and packed tower)*

distribution ratio
The ratio of the equilibrium concentrations of a given component in two immiscible solutions.

Doerner-Hoskins distribution law
The logarithmic law governing the distribution of activity between precipitate and solution in many coprecipitations of radioactive tracers with carrier precipitates. The law may be expressed .

$$D = \frac{\log(1-a)}{\log(1-b)}$$

where a is the fraction of tracer coprecipitated with fraction b of carrier and D is a constant characteristic of the system.

dollar (reactor engineering)
A term for the difference between the reactivities for a given reactor corresponding to the delayed critical and prompt critical conditions. One one-hundredth of a dollar is called a *cent*. *(See delayed-critical; prompt-critical)*

dominant character (genetics)
Of a pair of contrasted characteristics, the one which will appear in a hybrid resulting from cross-breeding of homozygous parents unlike with respect to that characteristic.

donut
(See doughnut)

Doppler broadening
The spreading of frequencies of radiation which is potentially all of the same frequency, with a consequent broadening of the corresponding spectral line, which results when the radiating atoms, molecules or nuclei do not all have the same velocity relative to the observer, so that each radiating particle may give rise to a different *Doppler shift*. For example, since the molecules of a luminous gas have a maxwellian distribution of velocities, and an average velocity that increases with temperature, each spectral line of the gas comprises a range of observed frequencies symmetrically distributed about the frequency for the atom at rest, this range increasing with increasing temperature; and there is a distribution of intensities throughout the broadened line that is determined by the maxwellian distribution of velocities. In absorption spectra, a similar broadening of the

lines can result from the motions, relative to the observer, of the absorbing atoms or molecules. In nuclear physics, thermal motions of the nuclei in the material under examination can contribute appreciably to the widths of resonance lines, many of which (for instance, in slow neutron absorption) have natural widths of about 1 ev.

Doppler shift
The change in frequency and wavelength of electromagnetic radiation caused by translational motions of the radiating atoms, molecules, or nuclei in the line of sight, and the corresponding displacement of lines in a spectrum of the radiation. According to the **Doppler principle,** the observed frequency is increased or decreased, depending on whether the motion is toward or away from the observer.

dose (or **dosage**) (radiobiology)
According to current usage, the radiation delivered to a specified area or volume or to the whole body. Units for dose specification are roentgens for x- or gamma rays, reps or equivalent roentgens for beta rays. The subject of dose units for particulate radiation and for very high energy x-rays has not been settled. In radiology the dose may be specified in air, on the skin, or at some depth beneath the surface; no statement of dose is complete without specification of location. The entire question of radiation dosage units is under consideration by the International Congress of Radiology, and it is expected that new units based on the energy absorbed in tissue will be adopted.

dose, air (x-rays)
(Radiobiology) X-ray dose expressed in roentgens delivered at a point in free air. In radiologic practice it consists only of the radiation of the primary beam, and that scattered from surrounding air.

dose, cumulative
The total dose resulting from repeated exposures to radiation of the same region, or of the whole body.

dose, depth
The radiation dose delivered at a particular depth beneath the surface of the body. It is usually expressed as percentage of surface dose or as percentage of air dose.

dose, exit
Dose of radiation at surface of body opposite to that on which the beam is incident.

dose, integral (or **volume dose)**
A measure of the total energy absorbed by a patient or any object during exposure to radiation. According to British usage the integral dose for x- or gamma rays is expressed in *gram-roentgens.*

dose, median lethal (MLD)
Dose of radiation required to kill, within a specified period, 50 per cent of the individuals in a large group of animals or organisms. *(See median lethal time)*

dose, percentage depth
Amount of radiation delivered at a specified depth in tissue, expressed as a percentage of the amount delivered at the skin, or as percentage of air dose.

dose, permissible
The amount of radiation which may be received by an individual within a specified period with expectation of no harmful result to himself. (Supersedes the term tolerance

dose.) For long-continued x- or gamma ray exposure of the whole body it is 0.3 r per week measured in air. (For detailed information, see National Bureau of Standards Handbook 59 and subsequent publications.)

dose, skin
Dose at center of irradiation field on skin. It is the sum of the air dose and *back scatter*, with the addition of the exit dose from other parts, if this is significant.

dose, threshold
The minimum dose that will produce a detectable degree of any given effect.

dose, tissue
Dose received by a tissue in the region of interest. In the case of x-rays and gamma rays, tissue doses are expressed in roentgens. At the present time there is no generally accepted unit of tissue dose for other ionizing radiations. In radiobiological studies it is customary to think of the tissue dose in terms of the energy absorbed per gram of tissue. Several units related to the roentgen have been suggested, such as the rep (*see roentgen equivalent, physical*) and *rad*.

dose, tolerance
A term based on the assumption that an individual can receive such a dose of radiation without any harmful effects. It is now superseded by **permissible dose**.

dose-effect curve
A curve relating the dose of radiation with the effect produced.

dose fractionation
A method of administration of radiation in which relatively small doses are given daily or at longer intervals.

dose meter, dosimeter
Any instrument which measures radiation dose.

dose meter, integrating
Ionization chamber and measuring system designed for determining total radiation administered during an exposure. In medical radiology the chamber is usually designed to be placed on the patient's skin. A device may be included to terminate the exposure when it has reached a desired value.

dose protraction
A method of administration of radiation by delivering it continuously over a relatively long period at a low dosage rate.

dose rate, dosage rate
Radiation dose delivered per unit time.

dose rate meter
Any instrument which measures radiation dose rate.

double-beta decay or disintegration
A type of radioactivity in which the atomic number changes by +2 and the mass number remains unchanged. It may occur when two beta particles are simultaneously emitted or when two electrons are simultaneously captured. Two neutrinos may or may not be emitted in this process. The process is theoretically possible, but very improbable.

doubling time
In a breeding reactor, doubling time in days =

$$\frac{1}{(C-1)\times \text{grams consumed per day per gram}}$$

where C is the number of fissionable nuclei formed for each fissionable nucleus lost.

doughnut, donut
(Reactors) Assembly of fissionable material of higher enrichment than that of the basic reactor, used in a thermal reactor to provide for experimental purposes a local increase in fast neutron flux. The assembly often is shaped like a doughnut. (Accelerators) An accelerating tube of toroidal shape.

down time
Time during which a machine or plant, such as a chemical processing plant or nuclear reactor, is not in operation. Down time may be required for maintenance, reloading, and the like.

drop model of nucleus
(See liquid-drop model of nucleus)

drying
The removal of relatively small amounts of water from liquids, gases or solids.

drying period, falling rate
In the drying of solids, a period in the later stages of drying during which the rate of moisture loss is decreasing.

dynamic condenser electrometer
(See vibrating reed electrometer)

E

edema (biology)
Presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body, or part of the body.

edge-cracks (metallurgy)
The cracks that occur at the edges of metal sheets during rolling.

effective atomic number
(See atomic number)

effective half-life
(See half-life)

effective simple process factor
(See simple process factor)

effective wavelength (x-rays)
Wavelength of monochromatic x-rays which undergo the same percentage attenuation in a specified filter as the heterogeneous beam under consideration. The term was originated by Duane; his specified filters were 1 mm Cu or 3 mm Al, and he determined attenuation of the monochromatic rays by means of a spectrometer.

efficiency (counters)
A measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably, so that it is well to make sure which factors (window transmission, sensitive volume, energy dependence, etc.) are included in a given case.

effluent
A stream leaving a process or a unit of process equipment.

Einstein-Bose statistics
(See quantum statistics)

elastic collision
(*See collision*)

elastic scattering
(See scattering)

electrolytic polishing (metallurgy)
The process of producing a smooth lustrous surface on a metal by making it the anode in an electrolytic solution and preferentially dissolving the protuberances.

electrometer
An instrument for measuring electrical charge; usually by mechanical forces exerted on a charged electrode in an electric field.

electrometer tube
A vacuum tube specially designed with a high input impedance and low grid current.

electron
An *elementary particle* of rest mass m_e equal to 9.107×10^{-28} gm and charge equal to 4.802×10^{-10} statcoulombs. Its charge may be either positive or negative. The positive electron is usually called a *positron;* the negative electron is sometimes called the *negatron.* Most frequently

the term electron means negatron. The negative electron is a constituent of all atoms. In a neutral atom the number of electrons is equal to the atomic number Z. The electron has an intrinsic magnetic moment $\mu = \mu_0 \left(1 + \frac{e^2}{hc}\right)$, where μ_0 is the *Bohr magneton*. It has a spin quantum number of ½ and is described by the Fermi-Dirac statistics. **A secondary electron** is an electron set in motion as the result of a transfer of momentum from primary radiation, which may be either electromagnetic or particulate.
(*See negatron; pair production; positron*)

electron capture
Radioactive transformation of a nuclide of atomic number Z and mass number A to the nuclide of atomic number Z-1 and mass number A, and in which a bound electron merges with the nucleus. It is a type of *beta decay*, and is represented by the symbol *E* or *E. C.* An example is $e^- + {}_{23}V^{49}_{26} \rightarrow {}_{22}Ti^{49}_{27} + \nu + Q$, $t_{1/2} = 600$ days, and the fundamental process involved is $p + e^- \rightarrow n + \nu$; that is, the proton *p* transforms to a *neutron n* within the nucleus, and a *neutrino ν* emerges with energy equal to the difference between the *disintegration energy Q* and the binding energy of the electron e^- before its capture. The electron usually comes from an atomic or molecular orbital of the atom or molecule containing the transforming nucleus, in which case the term **orbital-electron capture** is applicable. In a metal, it may be a conductivity electron. Capture of unbound electrons by nuclei has not been observed. *K-electron capture, L-electron capture*, . . . , refer to capture of electrons initially in the designated atomic shell. Following the removal of an inner-shell electron, *x-rays* and *Auger electrons* characteristic of the product element Z-1 are emitted, thus providing a means of observation of the process. Gamma rays may also be emitted when product nuclei are left in excited states. When sufficient energy is available, K-electron capture predominates over capture of less strongly bound electrons. If *Q* is less than the *K*-shell binding energy, but greater than the *L*-shell binding energy, *L*-electron capture occurs in the absence of K-electron capture. For $Q > 2\,m_e c^2$ [= 1.022 Mev], positron emission is a competing process. For light elements, electron capture is much less probable than positron emission, whereas for heavy elements the situation is reversed. It is thought that emission of a monoenergetic neutrino accompanies the process of electron capture.

electron collection
A technique in ion chamber measurements which takes advantage of the high mobility of free electrons as compared with ions.

electron diffraction instrument
(*See diffraction instrument*)

electron gun
A device for producing a collimated beam of electrons.

electron microscope
An instrument employing electron beams for making enlarged images of objects.

electron multiplier tube
A tube in which small electron currents are amplified by a cascade process employing secondary emission.

electron-positron pair
The electron and positron simultaneously created in the process called *pair production*.

electron radius, classical
Usually, the radius r given by the expression $r = e^2/m_e c^2 = 2.82 \times 10^{-13}$ cm, where m_e is the rest mass of the electron. This expression is obtained by equating the rest-mass energy $m_e c^2$ of the electron to its electrostatic self-energy, e^2/r.

electron transfer
The transfer of n electrons from a lower oxidation state of an element to a state n units higher in oxidation level. If one of the oxidation states is tagged isotopically, the transfer process gives the appearance of exchange of atoms.

electron volt, ev
A unit of energy equal to the energy gained by a particle having one electronic charge when it passes in a vacuum through a potential difference of 1 volt; 1 ev = 1.60×10^{-12} erg. *(See mass-energy equivalence)*

electrophoresis
The motion of collodial particles suspended in a fluid medium, under the influence of an electric field. (Biophysics) **cataphoresis** The migration of charged particles through a fluid under the influence of an electric field. (Radiobiology) **iontophoresis** The introduction of ions into the tissues of the body by the use of electric currents.

electroscope
An instrument for detecting an electric charge by means of the mechanical forces exerted between electrically charged bodies.

electrostatic generator
A high-voltage generator in which the potential is produced by the work done in mechanical transport of electrical charges. *(See Van de Graaff generator)*

electrostatic lens
An arrangement of electrodes so disposed that the resulting electric fields produce a focusing effect on a beam of charged particles.

element
1. A substance all of whose atoms have the same *atomic number.*
2. A naturally occurring mixture of *isotopes.*
3. A class of atom having a particular atomic number as the distinguishing characteristic.

elementary particle
A term loosely applied today to the electron, proton, neutron, positron, positive and negative mu mesons, positive, negative and neutral pi mesons, positive, negative and neutral V-particles, neutrino, and some similar entities the existence of which are speculative or which have not yet been thoroughly characterized by experiment. Photons are often included in this list, although a photon differs from the other elementary particles in that its set of intrinsic properties, such as spin and parity, are not fixed in value, but depend on the type of radiation field it represents. Originally the term elementary particle was applied to any particle of matter that was thought to have both a unique set of intrinsic properties and an independent and permanent existence; but it is now known that certain of these particles can convert into one or more other particles, as in the pi-mu decay of mesons, neutron decay, pair production, and conversion to annihilation radiation.

elutriation
1. The separation of the lighter particles of a powder from the heavier by means of an upward stream of fluid.
2. The desorption of ions from an ion-exchanger.

emanating power
The fraction of radioactive inert-gas atoms formed in a solid or solution that escapes.

emanation (Em)

1. A name commonly given to element 86. The nomenclature has not been settled definitely. The names **radon** and **emanon** are also used. The naturally occurring isotopes of mass 219, 220 and 222 are known as *actinon, thoron,* and *radon,* respectively. The longest lived isotope is 3.825*d* Em^{222} (Rn).
2. The escape of radioactive gases from the materials in which they are formed, e.g., radon from radium, krypton and xenon from a substance undergoing fission.

emanon
(See emanation)

embrittlement (metallurgy)
An increase in the susceptibility of a metal to fracture under stress caused by the introduction of gas or other foreign atoms, by segregation of brittle constituents, by internal oxidation, or by certain types of corrosion.

empirical mass formula
A *mass formula* (due to Bohr and Wheeler) that has less theoretical foundation than the *semiempirical mass formula,* but greater freedom for adjustment to fit empirical data. It may be written:

$$M(A,Z) = A(1+f_A) + \tfrac{1}{2}B_A(Z-Z_A)^2 + \Delta,$$

$$\text{with } \Delta = \begin{cases} +\tfrac{1}{2}\,\delta_A & \text{for even } A, \text{ odd } Z; \\ +\tfrac{1}{2}\,\epsilon_A & \text{for odd } A, \text{ odd } Z; \\ +\tfrac{1}{2}\,\epsilon_A & \text{for odd } A, \text{ even } Z; \\ +\tfrac{1}{2}\,\delta_A & \text{for even } A, \text{ even } Z; \end{cases}$$

see note sheet

Here $M(A,Z)$ is the mass of an atom of mass number A and atomic number Z, f_A is an idealized *packing fraction,* Z_A is the (nonintegral) atomic number of maximum stability for mass number A, and Δ is a term that reflects the "pairing energy" of like nucleons; f_A, B_A, Z_A, δ_A and ϵ_A are usually taken to be parameters varying smoothly with A and adjustable to give the best fit with experimental data. $\epsilon_A < \delta_A$. *(See semiempirical mass formula)*

emulsion, nuclear
A photographic emulsion specially designed to permit observation of the individual tracks of ionizing particles.

end product
The stable nuclide that is the final member of a *radioactive series.*

endoergic
A synonym for *endothermic.*

endosteum (biology)
The tissue lining the marrow cavity of bones.

endothelium (biology)
The layer of cells lining lymph and blood vessels.

endothermic, endoergic (adj.)
Involving an absorption of heat or other energy. An **endothermic nuclear reaction** is one in which the *reaction energy* (*Q-value*) is negative; the sum of the rest masses of the reactants is less than that of the products. Since the energy equivalent to the accretion in mass must be supplied by the bombarding particle or photon, an endothermic nuclear reaction is characterized by a *threshold energy.*

endurance limit, endurance ratio
(See fatigue)

energy, stored (metallurgy)
The potential energy of atomic displacements which is retained by a solid after plastic deformation or after irradiation. The energy may be measured by total combustion or by comparative specific heat determinations against a normal specimen of the same material.

energy dependence (instrumentation)
The characteristic response of a radiation detector to a given range of radiation energies or wavelengths, as compared with the response of a standard open air chamber.

energy unit (biophysics)
The dose received from ionizing radiation at a point in tissue when the energy absorbed is 93 ergs per gram at that point. (A proposed unit, Gray)

enhancement
(See separation factor)

enriched material
1. Material in which the amount of one or more isotopes of a constituent has been increased.
2. Uranium in which the abundance of the U^{235} isotope is increased above normal.

enriched reactor
A nuclear reactor in which the fuel may be uranium increased in U^{233} content beyond the normal isotopic concentration or other concentrated fuel such as plutonium or U^{235} or a combination of these.

enriching (chemical engineering)
The concentration of the more volatile component by a fractional distillation carried out above the feed point of a distillation column.

enrichment (reactor theory)
Any process which changes the isotopic ratio; in reference to uranium, it is a process which increases the ratio of U^{235} to U^{238} in uranium by separation of isotopes. Enrichment processes include thermal diffusion, gaseous barrier diffusion, and centrifugal and electromagnetic separation.

enrichment factor
The ratio of isotopic ratios after enrichment to that before enrichment. *(See separation factor)*

entrainment
The suspension of liquid droplets, gas bubbles or fine solid particles being carried by a stream of fluid.

epicadmium (reactor theory)
Energies above the cadmium cut-off (about 0.3 ev).

epilation, depilation (biology)
The temporary or permanent removal of hair.

epiphysis (biology)
A part or process of a bone which ossifies separately, and later becomes joined to the main part (diaphysis) of the bone. Growth of the bone as a whole can continue until the epiphysis becomes fused with the diaphysis.

epithelioma (biology)
Malignant neoplasm derived from epithelial cells lining the external and internal body surfaces. Some authorities prefer the term carcinoma for these growths.

epithelium (biology)
The purely cellular, non-vascular layer covering all the free surfaces of the body, cutaneous, mucous and serous, including the glands and other structures derived therefrom.

epithermal (reactor theory)
Above thermal. For normal temperatures, epithermal neutrons have energies up to a few electron volts.

epithermal neutrons
(See neutron)

epithermal reactor
(See nuclear reactor)

equilibrium diagram
(See phase diagram)

equilibrium orbit
(See stable orbit)

equilibrium time (isotopes separation)
Time required for the mole fraction in each stage to reach a value appropriate to the steady operating state.

equilibrium water
That water content of a solid which will remain unchanged by further exposure to air of a given humidity, temperature and pressure.

equivalence of mass and energy
(See mass-energy equivalence)

equivalent constant potential (x-rays)
The constant potential which must be applied to an x-ray tube to produce radiation having an absorption curve in a given material closely similar to that of the beam under consideration.

equivalent roentgen
(See roentgen equivalent, physical)

equivalent stopping power
(See stopping power)

erythema (biology)
An abnormal redness of the skin, due to distension of the capillaries with blood. It can be caused by many different agents, e.g., heat, certain drugs, ultraviolet rays, ionizing radiations.

erythrocyte (biology)
A red blood corpuscle.

esu
Electrostatic unit of quantity of either sign.

etching (metallurgy)
The process of revealing structural details by preferential attack of a metal surface. Etching may be performed chemically, electrolytically, by heating in a reactive atmosphere, or by preferential evaporation.

etiology (biology)
Sum of knowledge regarding causes of a disease or of other processes.

eutectic (metallurgy)
1. The isothermal, constant composition transformation of a liquid to more than one solid phase upon cooling.
2. The liquid alloy composition which undergoes the eutectic transformation and possesses the lowest freezing point in its range of composition.
3. The solid alloy, containing more than one phase, which results from the eutectic transformation.

ev
The symbol for *electron volt.*

evaporation
The removal by vaporization of relatively large amounts of liquids from solutions or suspensions.

evaporative centrifuge
A batch separating device wherein

a mixture to be separated is introduced into the centrifuge as a liquid. The vapors are removed from a point near the axis of the centrifuge, having been separated by diffusion through the centrifugal field.

even-even nuclei
Nuclei which contain an even number of protons and an even number of neutrons.

even-odd nuclei
Nuclei which contain an even number of protons and an odd number of neutrons.

exchange, chromosome
(See chromosome exchange)

exchange force
(See nuclear forces)

exchange reaction
(See isotopic exchange)

excitation
The addition of energy to a system, thereby transferring it from its *ground* state to an *excited* state. Excitation of a nucleus, an atom or a molecule can result from absorption of photons or from inelastic collisions with other particles or systems.

excitation curve
A curve showing the relative yield of a specified nuclear reaction as a function of the energy of the incident particles or photons. For a **thin-target excitation curve,** the ordinates are proportional to the cross sections for that reaction. Of less theoretical but greater practical importance, particularly when a product radioactivity is desired, is a **thick-target excitation curve** which is the curve for an infinitely thick target. *(See target)*

excitation energy
The energy required to change a system from its *ground* state to an *excited* state. With each different excited state there is associated a different excitation energy.

excitation function (nuclear)

1. The cross section for a specified nuclear reaction expressed as a function of the energy of the incident particle or photon.
2. A synonym for *excitation curve.*

excited (adj.)
(Of a state of a nucleus, an atom or molecule) having higher energy than the *ground* state.

exclusion principle
(See Pauli exclusion principle)

exit dose
(See dose, exit)

exothermic, exoergic (adj.)
Involving an evolution of heat or other energy. An **exothermic nuclear disintegration** is one in which the *disintegration energy (Q-value)* is positive; the sum of the rest masses of the reactants exceeds that of the products. The energy equivalent to the diminution in mass appears in the form of kinetic energy of the products and/or radiation. All radioactive processes are exothermic.

expansion ratio (cloud chamber)
The ratio of the volume of the cloud chamber gas after expansion to its volume before expansion.

exponential absorption
The removal of particles or photons from a beam, as it passes through matter, according to the relationship $I = I_0 e^{-\mu x}$, where I is the intensity of the beam, x is a measure of the amount of matter traversed, I_0 is the initial intensity, and μ is the appropriate *absorption coefficient.*

exponential decay
Decrease in the amount of a particu-

lar substance present according to the equation $A = A_0 e^{-\lambda t}$, where A and A_0 are the quantities present at times t and zero, respectively, and λ is a constant characteristic of the substance. For a radionuclide, λ is the *disintegration constant.*

exponential experiment (reactor theory)
An experiment with a subcritical assembly of fissionable material and moderator useful in determining neutron properties of reactor core structures. With the usual placement of the source of neutrons, and shape of assembly, the increase in neutron flux in one direction becomes exponential, hence the name exponential reactor.

exponential well
(See potential, nuclear)

exposure
(See dose)

exposure, acute (radiobiology)
Radiation exposure of short duration.

exposure, chronic (radiobiology)
Radiation exposure of long duration, by fractionation or protraction. *(See dose fractionation; dose protraction)*

extensive shower, giant air shower
A shower of many cosmic ray particles that extends over a large area (perhaps 100 m in diameter) and presumably is initiated high in the atmosphere by a single cosmic ray having energy that may be as high as 10^{15} to 10^{17} ev.

extract layer (chemical engineering)
The liquid layer in a solvent extraction system into which the desired solute is extracted.

extraction (chemical engineering)
The operation wherein a liquid or solid mixture is brought into contact with an immiscible or partially miscible liquid to achieve a redistribution of solute between the phases.

extraction tower (chemical engineering)
A tower containing packing, baffle plates or sprays arranged so as to provide intimate contact between the immiscible or partially miscible phases in an extraction process.

extractive distillation (chemical engineering)
Separation by distillation of a relatively non-volatile azeotrope formed from an added compound and one of the constituents of the original mixture.

extrapolated boundary (reactor theory)
The surface outside a medium on which the neutron flux would be zero if extrapolated from the flux a few mean free paths inside the medium.

extrapolated range
(See range, extrapolated)

extrapolation ionization chamber
(See ionization chamber extrapolation)

extrusion
The process of shaping a plastic substance, specifically a metal, into elongated forms by forcing it through a die with an opening having the cross section desired in the final product.

F

face-centered cubic (metallurgy)
A crystal structure characterized by a cubic unit cell with an atom at each corner and an atom in the center of each of the six faces. The unit cell contains four atoms. This structure and the *hexagonal close packed* structure correspond to the densest packing of spheres.

falling rate drying period
(See drying period, falling rate)

family (radioactivity)
(See radioactive series)

fast effect
The reactivity change due to fissions caused by fast neutrons in a thermal reactor.

fast fissions
Fission caused by fast neutrons.

fast neutrons
(See neutron)

fast reactor
(See nuclear reactor)

fatigue (metallurgy)
The tendency for a metal to fracture under repeated stressing considerably below the ultimate tensile strength. In a common method of test, a polished specimen is rotated rapidly and subjected to alternate flexure. The **fatigue limit** or **endurance limit** of a metal or alloy is that stress below which failure will presumably not occur in an infinite number of cycles. When such a limit does not exist, the term is often applied to the stress causing fracture in a specified large number of cycles. The **endurance ratio** is the endurance limit divided by the tensile strength. For most carbon and alloy steels this ratio is approximately 0.5, while for nonferrous alloys it may be less than 0.25 or greater than 0.5. Sharp notches reduce the endurance limit of most materials. Corrosion of the metal surface during the cyclic stressing leads to **corrosion fatigue,** and causes a pronounced decrease in the endurance limit in many metals.

Feather analysis (chemistry)
A technique established by N. Feather (1938) for the determination of the range in aluminum of the beta rays of a species by comparison of the absorption curve with the absorption curve of a reference species, usually Bi^{210} (RaE). It is assumed that the attenuation of the beta beam by the amount of absorber, expressed as a fraction of the range, is the same in the limit, for the beta particles under study as those of Bi^{210}. Taking the range for Bi^{210} as 476 mg/cm^2 of aluminum the attenuations of Bi^{210} radiations at 0.1, 0.2, 0.3, ... of this amount of absorber are used to identify trial values of the range of the species under study. These trial values are plotted against the numbers 0.1, 0.2, 0.3, ... and extrapolated to obtain a value at 1.0. Maximum beta energies may be estimated from these extrapolated range values, as for instance by an empiri-

cal equation given by Feather. *(See range-energy relation)*

Feather rule
An empirical relation between the range and energy of continuous beta rays.

feedback control system
A control system, comprising one or more feedback control loops, which combines functions of the controlled signals with functions of the commands to tend to maintain prescribed relationships between the commands and the controlled signals. *(See automatic control system)* [For automatic control or feedback control terminology, refer to ASME Standard 105, "Automatic Control Terminology," 1954, and "IRE Standards on Terminology for Feedback Control Systems," IRE Proceedings, Vol. 44, No. 1, January 1956.]

Fermi age
(See age)

Fermi-age model
A model for the study of the slowing down of neutrons by elastic collisions. It is assumed that the slowing down takes place by a very large number of very small energy changes. Phenomena due to the finite size of the individual energy losses are ignored.

Fermi constant
A universal constant, introduced in beta disintegration theory and often denoted by the symbol g, or G, that expresses the strength of the interaction between the transforming nucleon and the electron-neutrino field. Its value lies between 10^{-48} and 10^{-49} gm cm^5 sec^{-2}. *(See coupling constant)*

Fermi-Dirac statistics
(See quantum statistics)

Fermi plot
(See Kurie plot)

Fermi selection rules
(See selection rules)

fermion
A particle that obeys the Fermi-Dirac quantum statistics. *(See quantum statistics)*

fertile
Capable of being transformed into a fissionable substance by capture of a neutron. Common examples are thorium (Th^{232}) and uranium (U^{238}). Also the case in which the nucleus is capable of capturing a neutron and, after existing as an intermediate element of relatively short half-life, becomes a fissionable nucleus, uranium (U^{233}) from Th^{232} and plutonium (Pu^{239}) from U^{238}.

fertilization (biology)
Fusion of two gametes, male and female, to form a zygote.

Fick's law
The statement that the diffusion current density is proportional to the negative of the gradient of the neutron density. This is the basis of the elementary diffusion approximation.

field emission
The emission of electrons from unheated metal surfaces, produced by sufficiently strong electric fields.

film
(See boundary layer; laminar boundary layer)

film badge
An appropriately packaged photographic film for detecting radiation exposure of personnel; usually dental-size x-ray film, worn on the person, and frequently combined with an identification badge. The badge may contain two or three films of

different sensitivity, and it may contain a filter which shields part of the film from certain types of radiation. *(See film ring)*

film coefficient (chemical engineering)
The rate of transfer of heat or mass through unit area of gas or liquid film under unit driving force.

film ring
A *film badge* in the form of a finger ring.

filter
A term widely applied to many kinds of devices that permit selectively the passage through them of some kinds of matter or energy. (Reactor engineering) Different respective classes of filters may be used to transmit selectively different types of radiation energy, nuclear particles, frequencies of electromagnetic or acoustic vibration, or the like, or to remove suspended particles from a fluid. (Radiology) **primary filter** A sheet of material, usually metal, placed in a beam of radiation to absorb, as far as possible, the less penetrating components. **secondary filter** A sheet of material of low atomic number relative to that of the primary filter, placed in the filtered beam of radiation to remove characteristic radiation produced in the primary filter. *(See also Thoraeus filter)*

filtration
(Radiology) Removal of some components of a heterogeneous beam of radiation by passage through a sheet of material. The filtering effect of any substance depends on its *absorption coefficients* for photons of various energies. Any filter will remove definite proportions of radiation of all wavelengths, but always a greater fraction of the longer wavelengths, except near critical absorption regions of the material and in the region where pair production becomes predominant. *(See pair production)* (Chemical engineering) The separation of mist or finely divided solids from a fluid by passing the fluid through a porous **filter medium** upon which the solids to be removed are collected or in which they are entrapped. The compacted aggregate of solids collected on the filter cloth or other medium is the **filter cake.** The **filtrate** is the liquid that has passed through the filter. A **filter aid** may be finely divided solid material used either as a precoat on the filter medium or incorporated in the suspension to be filtered. In the latter case, it increases the permeability of the filter cake and may decrease its compressibility.

fine structure (optical spectroscopy)
The occurrence of a spectral line as a doublet, triplet, ..., owing to the interaction, or coupling, between the spin angular momentum and the orbital angular momentum of the electrons in the emitting atoms. (Alpha-particle spectroscopy) *(See spectrum (alpha-particle))*

fine-structure constant
A universal constant α, given by $\alpha = 2\pi e^2/ch = 7.30 \times 10^{-3} \approx 1/137$.

fissile
Fissionable. Fissile is more used in England and Canada than in the United States.

fission
The splitting of a nucleus into two more-or-less equal fragments. Fission may occur spontaneously or may be induced by capture of bombarding particles. In addition to the fission fragments, neutrons and gamma rays are usually produced during fission.

fission, nuclear
The division of a heavy nucleus into two approximately equal parts. For the heaviest nuclei the reaction is highly exothermic, the release of energy being about 170 Mev per fission. A well-known example is the fission of the compound nucleus formed when U^{235} captures a slow neutron. Other examples are the fissions U^{233} and Pu^{239} by the capture of slow neutrons. The approximate equality of the fission fragments distinguishes fission from such processes as *spallation,* in which relatively small fragments are ejected, leaving only one large residual nucleus. Fission has been induced by neutrons, charged particles, and photons. When induced by photons, it is called **photofission. Spontaneous fission** is fission that occurs without particles or photons entering the nucleus from the outside. For this rare mode of radioactive decay which occurs only in the heaviest elements, the half-lives for decay are without exception very long. **Ternary fission** is the splitting of the nucleus into three nuclear fragments; there is disagreement as to whether this term should be used for the often-observed type of fission in which a small charged nuclear fragment (such as a proton, alpha particle, triton, or Li^{8} nucleus) is emitted during the process of splitting into two massive fragments, or whether it should be reserved for splitting into three massive fragments, a process that has not been observed conclusively.

fission fragments
The nuclear species which are first produced when an atom such as U^{235} or Pu^{239} undergoes fission. In slow neutron fission the fragments are seldom equal in mass but generally fall into a heavier group with masses around 140 and a lighter group with masses around 95. The fragments are abnormally rich in neutrons (high n/p ratio) and decay to stability by successive β^- emissions, in decay chains, averaging 3 to 4 members.

fission neutrons
Neutrons that are emitted as a result of nuclear fission. **Prompt fission neutrons** are those that are emitted during fissions. **Delayed fission neutrons** are those emitted by fission products. In the fission of U^{235} by thermal neutrons, the average number of fission neutrons emitted per fission is 2.5; these neutrons exhibit a continuous spectral distribution in energy which shows a maximum at $\sim$ 1 Mev and extends to higher energies according to the expression $\sinh \sqrt{2E} \exp(-E)$. Of the fission neutrons from U^{235}, 0.7 per cent are delayed neutrons. (*See delayed neutrons*)

fission poisons
Fission fragments which have appreciable capture cross section for neutrons. A famous example is Xe^{135} which has an absorption cross section of 3.5 million barns for slow neutrons.

fission products
The nuclides produced by the fission of a heavy element nuclide such as U^{235} or Pu^{239}. Thirty-five fission product elements from zinc through gadolinium have been identified from slow neutron fission.

fission recoils
The fission fragments at the instant of separation.

fission spectrum
The distribution in energy of the neutrons arising from fission.

fission yield
The fraction of fissions, usually expressed as a percentage, that gives

rise to a specified nuclide or a group of isobars. Since there are two products per fission, the total of all fission yields for a given fission process is 200 per cent. The fission yield curve is different for each mode of induced fission. For example, the curve for slow neutron fission of U^{235} has broad maxima at mass numbers 95 and 139, the yields there being about 6 per cent, and between its peak there is a valley going down to about 0.01 per cent in the region of symmetrical fission ($A \sim 117$). The **independent fission yield** of a particular fission product is the fraction of fissions forming that nuclide directly, rather than through a precursor. The **chain fission yield** for a particular mass number is the sum of the independent fission yields for all isobars of that mass number.

fissionable
Having the property of certain atomic nuclei, such as some isotopes of uranium and plutonium, of capturing neutrons and thereupon splitting into two particles with great kinetic energy. The term properly is applicable to nuclei that undergo fission by neutrons of thermal energies; but it sometimes is applied loosely to cases where the neutron must be of high energy, as in saying that U^{238} is fissionable by fast neutrons. (*See fission, nuclear*)

fissioning distribution
The modified neutron energy spectrum obtained by assigning to each neutron a weight equal to the probability that its next collision will result in fission.

flooding point (chemical engineering)
The limiting flow rate in two-phase countercurrent flow through a column above which the column is inoperable due to irregular flow.

flow-through centrifuge
(See counter-current centrifuge)

fluidized reactor
A nuclear reactor in which the fuel has been given the properties of a quasi-fluid, e.g., by suspension of fine fuel particles in a carrying gas or liquid.

fluorescence
1. The emission of electromagnetic radiation by a substance as the result of an absorption of energy from some other radiation, either electromagnetic or corpuscular, and characterized by the fact that it occurs only so long as the stimulus responsible for it is maintained.
2. The electromagnetic x-radiation so produced.
3. In x-rays, characteristic x-radiation emitted as a result of absorption of x-rays of higher frequency. (*See phosphorescence*)

fluorescence yield
The probability that an atom whose electronic structure is excited will emit an x-ray photon rather than an Auger electron in the first transition. It is a number between zero and unity, characteristic of the particular state of excitation of an atom of a particular element. The K-shell fluorescence yield increases with increasing atomic number, and is the sum of the fluorescence yields for the $K \rightarrow L_{II}$, $K \rightarrow L_{III}$, ... transitions. For a given element, the K-shell, L-shell, . . . fluorescence yields are successively smaller. (*See x-rays; Auger effect*)

fluorescent screen
A sheet of material coated with a fluorescent substance emitting visible light when irradiated with ionizing radiation.

fluorography (photofluorography)
Photography of an image produced on a fluorescent screen.

fluoroscope (biophysics)
A fluorescent screen suitably mounted with respect to an x-ray tube for ease of observation and protection, used for indirect visualization of internal organs in the body or internal structures in apparatus or in masses of metal, by means of x-rays.

fluoroscopy
X-ray examination by means of a fluoroscope.

flux

1. For electromagnetic radiation, the power, or energy per unit time, passing through a surface.
2. For particles or photons, the number passing through a surface per unit time.
3. As commonly used in nuclear physics, the product nv, where n is the number of particles per unit volume and v is their mean velocity. Partial fluxes may be defined for particles characterized by such parameters as speed and direction.

flux converter
(See doughnut)

focal spot (x-rays)
The part of the target of the x-ray tube which is struck by the main electron stream.

focusing (instrumentation)
The action of electric and/or magnetic fields in directing accelerated particles along desired paths.

forbidden transition
A transition between two states of a quantum-mechanical system for which the change in the quantum numbers involved is such, under the appropriate *selection rules*, as to make the transition less probable than a competing *allowed transition*—other things (such as the energy change) being equal. For example, transitions involving changes of total angular momentum quantum number of two or more are frequently forbidden and will have a smaller probability of occurrence than a possible competing "allowed" transition involving a change of only one. Transitions involving successively less favorable changes in the quantum numbers in going from the initial to the final state are often called second forbidden, third forbidden, and so on.

fraction exchange
A number, varying from 0 to 1.0 denoting the progress of an isotopic exchange reaction, which is defined by the expression

$$f = \frac{S - S_0}{S_\infty - S_0}$$

where f is the fraction exchange and S, S_0 and S_∞ are the specific activities of one of the reactants at time t, zero-time and infinite time (i.e., at equilibrium), respectively.

fractional distillation
A distillation in which the distillates boiling in different temperature ranges are separately collected.

fractionating column
In fractional distillation, an apparatus designed to bring into intimate contact the rising vapor and falling liquid. *(See also plate column; packed tower)*

frame of reference
A set of lines or surface used as a system of reference for defining coordinates that describe positions, velocities, and so on. *(See center-of-mass system; laboratory system)*

francium (Fr)
An element, atomic number 87, the heaviest alkali metal, discovered in

1938 by Marguerite Perey and named for her country, France. She isolated 21*m* Fr^{223}, actinium K, from its parent Ac^{227}. Several other francium isotopes are known.

free air ionization chamber
(See ionization chamber, free air, open air)

free molecule diffusion
(See Knudsen flow)

free water
The amount of water removed in drying a solid to its equilibrium water content.

ft
The symbol for *comparative lifetime.*

fuel (reactor engineering)
Fissionable material of reasonably long life, used or usable in producing energy in a nuclear reactor. The term frequently is applied to a mixture, such as natural uranium, in which only part of the atoms are fissionable, if it can maintain a self-sustaining chain reaction under the proper conditions.

fuel assembly (reactor engineering)
A structure of fuel and (usually) other material used in some reactors. Its main purpose is to facilitate fabrication and the assembling of the core or active lattice, which contains a number of fuel assemblies.

fuel rod (reactor engineering)
A rod-shaped body of nuclear fuel or a long-slender fuel assembly prepared for use in a reactor. Short fuel rods are called slugs. *(See fuel assembly; slug)*

fundamental particle
A synonym for *elementary particle.*

G

G
In radiation chemistry the number of molecules produced or converted per 100 ev of energy absorbed.

galling (metallurgy)
The localized mutual seizure of two metal surfaces during sliding friction accompanied by the removal of metal particles from one or both surfaces.

gamete (biology)
A mature germ cell such as an unfertilized ovum or spermatozoon.

gamma ray (γ-ray)

1. A quantum of electromagnetic radiation emitted by a nucleus, each such photon being emitted as the result of a quantum transition between two energy levels of the nucleus. Gamma rays have energies usually between 10 kev and 10 Mev, with correspondingly short wavelengths and high frequencies. They are often associated with alpha and beta radioactivity, following transitions that leave the product nuclei in excited states; in general, they are more penetrating than alpha or beta particles. They also occur in isomeric transitions and in many induced nuclear reactions. A **gamma ray spectrum** consists of one or more sharp lines, each corresponding to an energy and intensity that are characteristic of the source.
2. Sometimes loosely, an x-ray photon of high energy, exceeding about 1 Mev, or an *annihilation radiation* photon, each of which differs from a gamma ray, in sense (1), only in its mode of origin.

gamma ray spectrometer
An instrument for determining the energy distribution of gamma rays.

gamma uranium
(See uranium)

Gamow-Teller selection rule
(See selection rules)

gas amplification (instrumentation)
The ratio of the charge collected in a counter tube or ionization chamber to the charge produced in the active volume by the preliminary ionizing event.

gas counter (radiation)
A counter in which the sample is prepared in the form of a gas and introduced into the counter tube itself.

gas flow counter (radiation)
A counter in which an appropriate atmosphere is maintained in the counter tube by allowing a suitable gas to flow slowly through the volume.

gas scrubbing
The contacting of a gaseous mixture with a liquid for the purpose of removing gaseous constituents or entrained liquids or solids.

gate (reactor engineering)
A movable barrier of shielding material used for closing a hole.

Gaussian well
(See potential, nuclear)

Geiger counter
Historically, a "point counter." By popular usage, a Geiger-Muller counter tube or such a tube together with its associated electronic equipment.

Geiger-Muller counter tube, Geiger-Muller tube
A gas-filled chamber usually consisting of a hollow cylindrical cathode and a fine wire anode along its axis. It is operated with a voltage high enough such that a discharge triggered by a primary ionizing event will spread over the entire anode until stopped by the reduction of the field by space charge.

Geiger-Nuttall relation
An empirical rule according to which the alpha particle range R and the disintegration constant λ of natural alpha-emitting radionuclides bear the relation $\log R = A + B \log \lambda$, where A is a parameter having a different value for the uranium, actinium and thorium series, and B is a constant which is the same for all the series. The relation was long useful for estimating unknown half-lives from ranges. Subsequently discovered alpha emitters, particularly those produced artificially, show considerable deviation from the relation; nor does current theory substantiate the relation except for the general trend.

Geiger region
The voltage interval for a counter tube in which the charge transferred per isolated discharge is independent of the number of primary ions produced in the initial ionizing event. *(See plateau characteristic)*

Geiger threshold
The lowest voltage applied to a counter tube for which all pulses produced in the counter tube are of substantially the same size, regardless of the size of the primary ionizing event.

gene (biology)
Fundamental unit of inheritance, which determines and controls hereditarily transmissible characteristics. Genes are arranged linearly at definite loci on *chromosomes*.

generation time
The mean time required for the neutrons arising from a fission again to produce fissions.

genetic effect of radiation (radiobiology)
Inheritable changes produced by the absorption of ionizing radiations. On the basis of present knowledge these effects are purely additive, and there is no recovery.

geometry (radiation)
The physical relationship and symmetry of the portions of an assembly. In neutron calculations, plane, cylindrical, and spherical geometries are arrangements having the corresponding symmetries. In cross-section measurements, good geometry refers to the case where very few detected neutrons have had only slight chance of suffering a collision in the target. In poor geometry almost all particles leaving the target are detected. Loosely, *geometry factor*, or geometry, refers to the experimental arrangement of source, counter and other equipment. *(See geometry, good; geometry, poor)*

geometry, good
In nuclear physics measurements, an arrangement of source and detecting equipment such that the use of finite

source size and finite detector aperture introduces little error. For example, consider the measurement of the reaction energy Q, in the reaction $A + B \rightarrow C + D + Q$. Here particles B are supposed to strike target nuclei A, releasing the disintegration particles D and producing the recoil nuclei C. The measurement of Q depends upon the measurement of the energy of the particles D, and this in turn is dependent on the angle of emission of D relative to the direction of incident particles B. The necessarily finite sizes of the target and the detector aperture introduce an uncertainty in this angle. Good geometry is said to prevail when the resultant uncertainty in the measurement of Q is not much larger than the errors introduced by other factors such as the target thickness and the energy inhomogeneity of the incident particles.

geometry, poor
In a nuclear experiment, an arrangement such that the angular aperture between the source and detector is large, thus introducing into the measurement of the energy of the particle a comparative large uncertainty for which a correction may have to be made by some kind of a subsidiary analysis. Use of poor geometry is sometimes necessary so as to obtain sufficient intensity.

geometry factor (radiation)
The average solid angle at the source subtended by the aperture or sensitive volume of the detector, divided by the complete solid angle (4π). Frequently used loosely to denote counting yield or counting efficiency.

germ cells (biology)
The cells of an organism whose function it is to reproduce the kind. They are characteristically haploid.

giant air shower
A synonym for *extensive shower*.

gonad (biology)
An ovary or testis, site of origin of eggs or spermatozoa.

grain (metallurgy)
The individual crystal in a polycrystalline metal. The shape of the grain is influenced by the presence of contiguous grains. The size of grains may be varied between wide limits by appropriate heat treatment following cold-working, by hot-working, or by phase transformation.

gram-roentgen (radiobiology)
The unit is defined by Mayneord as the real energy conversion when a dose of one roentgen is delivered to one gram of air (about 84 ergs). The unit is employed, however, to describe total energy absorption by the patient in the course of therapy. The quantity obtained by integrating gram-roentgens throughout a region is called the integral dose. Thus, the integral dose, measured in gram-roentgens, resulting from irradiation of a patient with one roentgen of x-rays, will vary with the quality of the radiation, the size of the fields, and the thickness of the part. (A proposed unit, Mayneord)

granulocyte (biology)
White cell of bone marrow or blood stream containing conspicuous granules in the cytoplasm. According to the chemical affinity of these granules, these leucocytes are subdivided into neutrophil, basophil or eosinophil granulocytes.
(*Note:* Other blood cells may contain granules but these are usually less conspicuous than in the granulocytes.)

granulocytopenia (biology)
Decrease in number of granulocytes in the blood. *(See agranulocytosis)*

graphite
A form of carbon in which the atoms are hexagonally arranged in planes.

(Reactor engineering) The form of carbon commonly used for moderators because it can be made in compact, fairly strong blocks and can be machined easily to close tolerances and because the prolonged baking at high temperature used in its manufacture contributes to elimination of impurities that might absorb neutrons. *(See carbon)*

graveyard
Same as *burial ground.*

gravity segregation
(See segregation)

Green's function
(See kernel)

grenz rays
X-rays produced in the region of 5 to 20 kv.

ground (adj.)
(Of a state of a nucleus, an atom or a molecule) that of lowest energy. *(Syn. normalized)* All other states are termed *excited. (See excitation)*

ground state disintegration energy
(See alpha disintegration energy; beta disintegration; disintegration, nuclear)

growth curve

1. An *activity curve* in which the activity increases with time, or that portion of an activity curve showing such an increase.
2. A theoretical or experimental curve showing, as a function of time, the number of atoms, or the mass, or the activity of a nuclide being produced in a radioactive transformation or in an induced nuclear reaction.

guard ring (instrumentation)
An auxiliary electrode in a counter tube or ionization chamber to control potential gradients, reduce insulator leakage and/or define the sensitive volume.

guide field (betatron, synchrotron)
The magnetic flux which is provided to hold the particles in a stable circular orbit during the accelerating period.

gunk (chemical engineering)
A slang term denoting an undesirable nondescript material usually semisolid.

gyromagnetic ratio, nuclear
The quantity g given by $g = \mu/I$, where μ is the magnetic moment of the nucleus and I is the nuclear angular momentum quantum number. *(See nuclear magnetic resonance)*

H

$H\rho$
Symbol for magnetic rigidity.

$\hbar$, Dirac h
The symbol, usually pronounced "$\hbar$-bar," for the universal constant $h/2\pi$, where h is the *Planck constant.*

half-life
The average time $t_{1/2}$ required for the decay of one-half the atoms of a sample of a radioactive substance. Each radionuclide has an unique half-life, which is related to its *disintegration constant* λ and *mean life* τ as follows:

$$t_{1/2} = \ln 2/\lambda = 0.693/\lambda = 0.693\ \tau.$$

(See radioactive half-life)

half-life, effective (radiobiology)
Half-life of a radioactive isotope in a biological organism, resulting from the combination of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life} \times \text{Radioactive half-life}}{\text{Biological half-life} + \text{Radioactive half-life}}$$

half-thickness
The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value. It may be expressed in units of length or of mass per unit area. In a case of *exponential absorption*, the half-thickness $d_{1/2}$ is related to the appropriate (linear or mass) *absorption coefficient* μ as follows:

$$d_{1/2} = \ln 2/\mu = 0.693/\mu$$

half-time of exchange (chemistry)
The time required for half the net realizable exchange of atoms in a chemical exchange reaction to take place.

half-value layer (radiobiology)
The thickness of any particular material necessary to reduce the dose rate of an x-ray beam to one-half its original value.

haploid (biophysics)
Having a single complete set of chromosomes, the condition of the gamete nucleus. Opposed to *diploid.*

hard component of cosmic rays
That portion of cosmic radiation which penetrates a moderate thickness of an absorber (usually 10 cm of lead). The hard component, except near the top of the atmosphere, consists of mesons to a predominant degree, but includes some fast protons and fast electrons. *(See cosmic rays)*

hardness (metallurgy)
A property defining resistance to deformation, whose value depends upon the method of measurement. The devices used generally measure the ability of a metal to resist local indentation by a tool of fixed geometry and material under a specified constant static load, or the rebound

produced by the metal upon a freely falling hammer. The Brinell, Vickers, Rockwell and Knoop hardness testers are of the indentation type. The scleroscope tester is of the rebound type. (X-rays) A term for qualitatively specifying the penetrating power of x-rays. In general, the shorter the wavelength the harder the radiation.

health physics (radiobiology)
A term in common use for that branch of radiological physics dealing with the protection of personnel from harmful effects of ionizing radiation. It includes the routine procedures of radiation protection surveys, area and personnel monitoring, the recommendation of appropriate protective equipment and procedures, the determination of acceptable standards of operation, and the solution of problems incident to the effective and practical protection of all persons from harmful effects of radiation. Out of this last phase has grown the study of environmental hazards, including the accumulation of radioactive material by plants and animals, and possible injury to human beings ultimately utilizing these in food.

heat flush (isotopes separation)
A method of separating a mixture of He^3 and He^4 by means of a flow of heat in super-fluid helium.

heat treatment (metallurgy)
A combination of timed heating and cooling operations performed upon a solid metal or alloy in order to obtain desired structures or properties. Heating of a metal for the sole purpose of hot working is not included in this definition.

heavy-aggregate
(See concrete)

heavy-aggregate shield
A shield of heavy-aggregate concrete. *(See concrete)*

heavy hydrogen, deuterium
(See deuterium; hydrogen)

heavy meson
(See meson)

heavy water
1. Water in which the hydrogen of the water molecule consists entirely of the heavy hydrogen isotope of mass 2.
2. Written D_2O. Density, 1.1076 at 20° C. It is used as a moderator in certain types of nuclear reactors.
3. The term is sometimes applied to water whose deuterium content is greater than natural water. *(See water)*

heel (chemical engineering)
1. Commonly the residue remaining after a batch distillation has been carried through to completion; still bottoms.
2. Any material remaining in a vessel after removal of the main portion of the contents.

Heisenberg principle of indeterminancy, or of uncertainty
(See indeterminancy principle)

helium (He)
An element, second in the atomic series. It exists as a monatomic gas except at extremely low temperatures. Because it is chemically inert and has practically no absorption cross section for neutrons, it has been proposed for use as a reactor coolant.

helium age
(See age)

helvite
A mineral, complex silicate of beryllium, manganese, and iron. It is the

most plentiful potential ore of beryllium but is of low grade.

hemoglobin (biology)
The oxygen-carrying pigment of the red blood corpuscles.

heterogeneous reactor
(See nuclear reactor)

heterozygous (biology)
Derived from germ cells genetically unlike.

HETS (HETP) (chemical engineering)
"Height equivalent to a theoretical stage (plate)": the height of a column in which, for a given mixture, type of column, and method of operation, the degree of separation is that attainable with one theoretical stage (plate).

hexagonal close-packed (metallurgy)
A crystal structure that may be considered to have the form of a hexagonal right prism with an atom at each corner, an atom in the centers of each of the basal planes, and three atoms located on the corners of an interior equilateral triangle. The unit cell is a right prism with rhombic bases and contains two atoms. This and the *face-centered cubic* structure correspond to the densest packing of spheres.

high-flux reactor, high temperature reactor
(See nuclear reactor)

high-pressure cloud chamber
(See cloud chamber, high pressure)

hit theory
(See target theory)

hold-back agent, hold-back carrier (chemistry)
The inactive isotope or isotopes of a radioactive element(s) or an element of similar properties or some reagent which may be used to diminish (hold back) the amount of the radionuclide coprecipitated or adsorbed on a particular carrier or adsorbent. The hold-back agent because of its relatively high concentration compared to the radionuclide is presumed to play the major role in saturating the "active" spots on the carrier or adsorber, thus reducing the amount of the radionuclide carried or adsorbed.

hold-up (isotopes separation)
The total amount of process material tied up in a separation plant, or in some component thereof; usually in reference to the amount of desired isotope.

homogeneous reactor
(See nuclear reactor)

homozygous (biology)
Derived from germ cells genetically alike.

hot
A colloquial term meaning highly radioactive.

hot atom
An atom which has high internal energy or high kinetic energy as a result of a nuclear process (such as beta decay, neutron capture, etc.).

hot atom chemistry
The chemical reactions and properties of atoms which are in a high state of excitation or possess high kinetic energy as a result of nuclear processes.

hot cave, hot cell
(See hot laboratory)

hot laboratory
A laboratory designed for research with radioactive materials where the strengths of radioactive sources are so high (say 50 millicuries and up) that special precautions in handling

are required. Such a laboratory will have shielded storage spaces (often called **hot cells** or **hot caves**), ventilation systems and experimental spaces designed to prevent escape of airborne activity, and provision for manipulating equipment remotely from behind a shield; and there will be a health-physics organization and other provisions to prevent excessive exposure of personnel by establishing procedures to be used, monitoring the radioactivity in working areas, measuring the exposure of personnel, etc.

hot-pressing
The process of compressing metal or other powders in a die at elevated temperatures. Sintering usually occurs during the pressing process.

HTO
Water labeled with *tritium*.

HTU (chemical engineering)
"Height of a transfer unit": in the theory of packed columns, the ratio of the superficial mass velocity to the mass transfer coefficient per unit volume. It is the rate at which material is entering a unit volume divided by the rate at which transfer between phases would occur with unit driving force.

hydrogen (H)
An element, first in the atomic series. In its ordinary compound with oxygen, water (H_2O), it is important as a coolant, solvent, and moderator. It has two naturally occurring isotopes, of atomic weights 1 and 2. The first is ordinary or **light hydrogen**. The second is **heavy hydrogen** or *deuterium*. Light hydrogen has the greater slowing-down power, but heavy hydrogen has lower neutron capture cross section. (*See deuterium; water*)

hydrogenous
Containing a high percentage of hydrogen and therefore effective (reactor engineering) in the slowing-down of neutrons. *(See moderator)*

hyperfine structure

1. For a single nuclide, the occurrence of the spectral lines as doublets, triplets, ..., owing to the interaction, or coupling, of the total angular momentum of the orbital electrons with the spin of the nucleus and associated magnetic moment.
2. For an element consisting of several isotopes, the occurrence for each spectral line, of components that are observable under high resolution; each isotope contributes one or more components. This type of structure is sometimes called **isotope structure** to distinguish it from the hyperfine structure of definition (1). Mixtures of even-*A* isotopes of an even-*Z* element can yield lines that show isotopic structure alone, since all such nuclides apparently have zero nuclear spin.

hyperon
An elementary particle having a rest mass intermediate in value between that of a neutron and that of a deuteron. All known hyperons are unstable. The currently recognized hyperons are listed in Table I. Hyperons are usually designated by capital Greek letters. *(See meson)*

I

"I" neutrons
Neutrons of such energy that they are strongly absorbable by iodine, that is, of energy in the neighborhood of 36 ev. This term is now obsolete.

ideal cascade
(See cascade, ideal)

ideal simple process factor
(See simple process factor)

image reactors (reactor theory)
When the method of images is used in solving the criticality equations for a reactor, the mathematically introduced new reactors are called image reactors.

impact parameter
1. In elastic scattering, the perpendicular distance from the initial position of the scattering center to the initial line of motion of the scattered particle.
2. By extension, in any nuclear reaction, the perpendicular distance from the target nucleus to the initial line of motion of the incident particle. *(See scattering)*

impact strength (metallurgy)
A property which is measured by the energy absorbed by a metal specimen when it is fractured at high velocity. The test is usually performed upon standard notched specimens. *(See charpy test; izod test)*

implant
1. (Radiology) Radioactive material in a suitable container, to be embedded in a tissue for therapeutic purposes. It may be permanent, **seed**, or temporary, **needle**.
2. (Biology) Tissue or organ removed to an abnormal position; a graft.

importance function (reactor theory)
A measure of the importance to the chain reaction in a nuclear reactor of a neutron at a given position and with a given velocity. The relative importance of two types of neutrons, A and B, is given by the number of neutrons of type A that must be supplied to make up for the removal of one neutron of type B, the process so being carried out that the level of the chain reaction is not affected. The *iterated fission expectation* is a particular normalization of the importance function.

impulse generator
A device for producing very short pulses of high voltage, usually by charging capacitors in parallel and discharging them in series.

in-pile test (reactor engineering)
Irradiation test in which the effects of radiation are measured while a specimen is subjected to radiation and neutrons in a reactor.

inclusions (metallurgy)
Particles of impurities (usually oxides, sulfides, silicates and such) that are trapped during freezing, or are formed during freezing or by subsequent reaction within the solid metal.

incoherent scattering
(See scattering)

incompressible flow
The flow of a fluid under conditions such that its density remains substantially constant.

independent fission yield
(See fission yield)

independent (individual) particle model of nucleus
A nuclear model based on the postulate that each nucleon moves independently in the field corresponding to the average positions of the rest of the nucleons. When supplemented with other postulates, including the Pauli exclusion principle and the existence of strong spin-orbit coupling, this model has been quite successful in explaining many empirical features of nuclei, such as shell structure, *magic numbers*, nuclear moments, and nuclear *isomerism*.

indeterminancy principle (uncertainty principle)
A postulate of quantum mechanics which asserts that in the simultaneous determination of the values of two canonically conjugate variables, the product of the smallest possible uncertainties in their values is of the order of magnitude of the Planck constant h. If Δq is the range of values that might be found for the coordinate q of a particle, and Δp is the range in the simultaneous determination of its momentum p, then $\Delta p \cdot \Delta q \approx h$. Similarly, if ΔE and Δt are the uncertainties in the simultaneous determination of the energy E and the time t, respectively, then $\Delta E \cdot \Delta t \approx h$; this formulation is useful in determining the lifetimes of extremely short-lived states.

indicator
A synonym for *tracer* previously introduced but now less frequently used.

individual particle model of nucleus
A synonym for *independent particle model of nucleus.*

induced nuclear disintegration
(See reaction, nuclear induced)

induced radioactivity
Radioactivity that is produced by nuclear reactions. *(See reaction, nuclear)*

induction accelerator
(See betatron)

inelastic collision
(See collision)

inelastic scattering
(See scattering)

inherent filtration (x-rays)
The filtration introduced by the wall of the x-ray tube and any permanent tube enclosure; to be distinguished from added primary and secondary filters.

inhour
A measure of reactivity. If zero reactivity is defined as that reactivity which causes the reactor to operate with constant power (infinite period), a reactivity of one inhour will result in a stable period of one hour. For a reactor which is very nearly critical, the reactivity in inhours is the reciprocal of the period in hours.

initial creep
(See creep)

inner bremsstrahlung
1. A process occurring infrequently in beta disintegration and resulting in the emission of a photon of energy between zero and the maximum energy available in the transition. The sudden change in the electric field in the region of the nucleus of the atom undergoing disintegration sometimes

results in the production of a photon, in a manner analogous to the emission of a photon in the ordinary (*outer*) *bremsstrahlung* process. In negatron or positron emission the energy of the photon comes at the expense of the electron-neutrino pair, and the spectral distribution decreases continuously with increasing energy to zero at the limiting energy of the beta particles. In electron capture the photon energy comes at the expense of the neutrino, and the spectral distribution is a maximum at about one third of the normal neutrino energy and goes to zero at zero energy and at the normal neutrino energy. The number of photons per disintegration ranges from 10^{-6} to 10^{-3}, depending on the energy, atomic number, and type of disintegration.

2. Sometimes, the radiation resulting from the inner bremsstrahlung process. *(See bremsstrahlung)*

insensitive time (counters)
(See dead time)

instrument range (of reactor operation)
An intermediate range of reaction rate in a nuclear reactor, above the counter range and below the power range, in which the neutron flux can be measured by the permanently installed control instruments such as ion chambers. Also called **period range** because in this range the period, rather than power level, is the important quantity to measure. (*See counter range; power range; period meter*)

integral dose
(See dose, integral)

integrating dose meter
(See dose meter, integrating)

integrating ionization chamber
(See ionization chamber, integrating)

intensifying screen (radiobiology)
Sheet of cardboard or other substance coated with fluorescent material, placed in contact with the film in radiography. The x- or gamma rays excite the fluorescent substance and the light thus emitted adds to the radiation effect on the film and produces an image of greater density for a given exposure. Sheets of thin lead may be used for the same purpose in industrial radiography with very high energy radiation. In this case the increased effect is due largely to secondary electrons and x-rays emitted by the lead.

intensitometer
A device for determining relative x-ray intensities during radiography, in order to control exposure time.

intensity

1. Of radiation, the energy of the number of photons, or of particles, passing through unit area perpendicular to the line of propagation at the point in question, in unit time. For parallel radiation, the area refers to a surface normal to the direction of propagation. In radiology, this term is often used incorrectly in the sense of *dose rate*.
2. Of any source of particles, the total number of particles emitted, or passing through, a unit area per unit of time.
3. Of radioactivity, a synonym for *activity* (df. 1).

interchange (chemistry)
The mixing of tracer, and added isotopic carrier such that the two participate to the same degree in any chemical reaction, showing that mixing has occurred in whatever chemical forms the tracer may have originally been distributed.

interlock (reactor engineering)
A device, usually electrical and (or) mechanical in nature, to prevent ac-

tivation of a control until a preliminary condition has been met, or to prevent hazardous operations. Its purpose usually is safety of personnel or equipment. For example, an interlock may be provided to prevent withdrawing control rods to start reaction in a pile until flow of coolant has been established. *(See start-up procedure)*

intermediate circuit
(See thermal cycle)

intermediate neutrons
(See neutron)

intermediate reactor
(See nuclear reactor)

internal conversion
(See conversion, internal)

internal conversion coefficient
(See conversion fraction; conversion ratio)

inventory
The total amount of any quantity present in a reactor at some instant of time. The **neutron inventory** is the total number of neutrons present; the **fissionable material inventory,** the total amount of fissionable material present.

inverse voltage (x-ray tube)
The voltage impressed across the x-ray tube during the half cycle when the anode is negatively charged.

inversion, chromosome
(See chromosome inversion)

ion
A charged atom or molecularly bound group of atoms; sometimes also a free electron or other charged subatomic particle. An **ion pair** consists of a positive ion and a negative ion (usually an *electron)* having charges of the same magnitude and formed from a neutral atom or molecule by the action of radiation. A **primary ion pair** is an ion pair produced directly by the causative radiation. An ion cluster is a group of ion pairs produced at or near the site of a primary ionizing event; it includes the primary ion pair and any secondary ion pairs formed, as by a *delta ray.*

ion beam scanning (isotopes separation)
The process of analyzing the mass spectrum of an ion beam either by changing the electric or magnetic fields of the mass spectrometer or by moving a probe.

ion density
The number of ion pairs per unit volume.

ion exchange
A chemical process involving the reversible interchange of ions between a solution and a particular solid material (**ion exchanger**) such as an ion exchange resin consisting of a matrix of insoluble material interspersed with fixed ions of opposite charge.

ion pair
A positive ion and a negative ion (usually, an electron) that have charges of the same magnitude and are formed from a neutral atom or molecule by the action of radiation. A **primary ion pair** is an ion pair produced by a primary particle or *photon.*

ion-pair yield
The quotient of the number of molecules, M, of a given kind produced or converted, divided by the number, N, of ion pairs resultant from high-energy radiation. The M/N ratio.

ion source (ion accelerator)
A device for generating ions to be accelerated.

ion yield
The number of ion pairs produced per incident particle or quantum.

ionium (Io)
The common name for 8.0×10^4y Th^{230}, a member of the *uranium series.*

ionization
Any process by which a neutral atom or molecule loses or gains electrons, thereby acquiring a net charge; the process of producing ions. *(See avalanche)*

ionization, columnar (biophysics)
Regions of such dense ionization that even a strong external electric field cannot prevent some recombination. The term refers usually to ionization produced by alpha particles.

ionization, total

1. The total electric charge on the ions of one sign when the energetic particle that has produced these ions has lost all of its kinetic energy. For a given gas the total ionization is closely proportional to the initial energy and is nearly independent of the nature of the ionizing particle. It is frequently used as a measure of particle energy.
2. The total number of ion pairs produced by the ionizing particle along its entire path.

ionization chamber
A device consisting of an enclosed or defined volume of gas between electrodes which may be charged or connected to a voltage source to produce an electric field throughout the volume, and intended for use in measuring quantity of ionizing radiation in terms of the electric charge associated with ions produced in the volume.

ionization chamber, air-wall (x- or gamma rays)
(Biophysics) Ionization chamber in which the materials of the wall and electrodes are so selected as to produce ionization essentially equivalent to that in a free air ionization chamber. This is possible only over moderate ranges of photon energies. Such a chamber is more appropriately termed an **air-equivalent ionization chamber.** *(See ionization chamber, free air, open air)*

ionization chamber, free air, open-air (radiobiology)
An air-filled ionization chamber in which a delimited beam of radiation passes between the electrodes without striking them or other internal parts of the instrument, and so arranged as accurately to define a sensitive volume of such magnitude that the secondaries are produced only in air and are fully utilized. The electric field is maintained perpendicular to the electrodes in the collecting region; as a result the ionized volume can be accurately determined from the dimensions of the collecting electrode and the limiting diaphragm. This is the basic standard instrument for x-ray dosimetry at least within the range from 5 to 1400 kv.

ionization chamber, integrating
An ionization chamber whose collected charge is stored in a capacitor for subsequent measurement.

ionization chamber, tissue equivalent (radiobiology)
An ionization chamber in which the material of the walls, electrode, and gas are so selected as to produce ionization essentially equivalent to that characteristic of the tissue under consideration. In some cases it is sufficient to have only tissue equivalent walls, and the gas may be air, provided the air volume is

negligibly small. The essential requisite in this case is that the contribution to the ionization in the air made by ionizing particles originating in the air is negligible compared to that produced by ionizing particles characteristic of the wall material.

ionization chamber extrapolation (radiobiology)
An ionization chamber designed to make a series of measurements, in which one factor is varied in suitable steps. The data derived from these measurements are plotted in appropriate form and the desired result is obtained by extrapolation of the curve. The construction of such a chamber depends on the problem to be investigated.

In general the chamber consists of two electrodes (plane, cylindrical, or spherical) uniformly separated from each other. One of the electrodes has an ion-collecting surface of known area and a guard plate or ring to insure proper electric field distribution. The ion-collecting volume is defined by the collecting area and the separation of the electrodes.

In the measurement of tissue dose, where it is necessary to determine the ionization in an infinitely small air cavity, the separation of the electrodes is changed in steps from a minimum practical value to a value that will provide a good curve for extrapolation to zero electrode separation (that is, zero collecting volume).

In an extrapolation chamber designed for the measurement of the dose at the surface of the skin in x-ray therapy, the electrodes are parallel planes and the one on the incident side of the beam can be varied in thickness. A double extrapolation can then be performed: (i) with respect to electrode separation and (ii) with respect to electrode thickness.

ionization counter (instrumentation)
An ionization chamber which has no internal amplification by gas multiplication and which is used for counting ionizing particles. *(See pulse ionization chamber)*

ionization current
The electric current resulting from the motion of ions and electrons produced in a sensitive volume (as of a chamber) by radiation.

ionization density
Number of ion pairs per unit volume.

ionization path (track)
The trail of ion pairs produced by an ionizing particle in its passage through matter.

ionization potential
For a particular kind of atom, the energy per unit charge, usually expressed in volts, required to remove an electron from the atom to an infinite distance. The **first ionization potential** is that for the removal of the most loosely bound electron from an initially neutral atom; the **second ionization potential** pertains to the removal of the most loosely bound electron from an atom from which one electron has already been removed; and so on. The work done in removing an electron from the atom, when expressed in electron volts, is numerically equal to the corresponding ionization potential expressed in volts. Thus, for the helium atom, the work done in removing one of the two electrons to infinity is 24.54 ev, and thus the first ionization potential of helium is 24.54 volts.

ionizing energy
The average energy lost by an ionizing particle in producing an ion pair in a gas. For air it is about 32 ev.

ionizing event (radiation)
Any occurrence of a process in which an ion or group of ions is produced; for example, the passage of a charged particle.

ionizing particle
A particle that directly produces **ion pairs** in its passage through a substance. In practice it is a charged particle having considerably greater kinetic energy than the *ionizing energy* appropriate to the medium.

ionizing radiation
Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

iontophoresis
(See electrophoresis)

irradiation
1. The exposure of material to x- or gamma radiation or slow neutrons.
2. The exposure of material in a nuclear reactor.
3. Bombardment.

(Radiobiology) Exposure to radiation. One speaks of *radiation therapy*, but of irradiation of the patient.

isobar (nuclear)
One of several nuclides having the same number of nucleons in their nuclei and hence having approximately the same atomic mass. For example, P^{32} and S^{32} are isobars. Commonly, one of several nuclides of the same mass number but different atomic numbers.

isobaric space
(See isobaric spin quantum number)

isobaric spin quantum number
A nuclear quantum number based on the view that the proton and the neutron are different states of the same elementary particle, the *nucleon*. The nucleon is assigned an isobaric spin quantum number of $\frac{1}{2}$ and its two possible orientations, $\tau_z = +\frac{1}{2}$ and $-\frac{1}{2}$, are assigned to the neutron and proton, respectively. The isobaric spin vectors of all the nucleons in a nucleus combine in the same manner as do angular momentum vectors, to yield a total isobaric spin vector $T = \sum\tau$ with an orientation $T_z = \sum\tau_z$. The symbolic space in which these orientations occur is called **isobaric space**; its z-axis corresponds to the direction of observable (negative) charge. Nuclei having a common value of T_z have the same *neutron excess*; equal to $2T_z$, since

$$T_z Z = N\,(+\tfrac{1}{2}) + Z\,(-\tfrac{1}{2}) = \tfrac{1}{2}\,(N-Z)$$

Both T and T_z are integral for even values of A and half-integral for odd values. A series of isobaric nuclei may each have a state with the same value of T and a different value of T_z, with $-T \leqslant T_z \leqslant T$. There is evidence that isobaric spin is conserved in some nuclear reactions. *(Syn. isotopic spin quantum number; isotopic variable)*

isodiaphere
One of several nuclides having the same difference between the numbers of neutrons and protons in their nuclei. For example, ${}_{90}\mathrm{Th}^{234}_{144}$ and ${}_{92}\mathrm{U}^{238}_{146}$ are isodiapheres.

isodose chart (radiobiology)
Chart showing the distribution of radiation in a medium by means of lines or surfaces drawn through points receiving equal doses. Isodose charts have been determined for beams of x-rays traversing the body, for radium applicators used for intracavitary or interstitial therapy, and for working areas where x-rays or radioactive isotopes are employed.

isomer, nuclear
One of two or more nuclides having the same mass number A and atomic number Z, but existing for measurable times in different quantum states

with different energies and radioactive properties. The state of lowest energy is the **ground state.** Those of higher energies are **metastable states.** To indicate the metastable isomer, the letter *m* is added to the mass number in the symbol for the nuclide; thus Br^{80m}. Commonly, the isomer of higher energy decays to one with lower energy by the process of *isomeric transition.*

isomer separation
The chemical separation of the lower energy member of a pair of nuclear isomers from its higher energy precursor made possible by chemical changes occurring as a result of the atomic or molecular excitation associated with the *isomeric transition.*

isomeric transition
A radioactive transition from one nuclear isomer to another of lower energy, often abbreviated I.T. The de-excitation of the nuclei in the metastable state may occur by gamma emission or by internal conversion followed by emission of x-rays and/or Auger electrons. It is a type of *forbidden transition. (See isomer, nuclear)*

isomerism, nuclear
The occurrence of nuclear isomers. *(See isomer, nuclear)*

isomorphism, isomorphous, isostructural
Substances exhibit isomorphism in the strictest sense when they have analogous crystalline structures and are mutually soluble in the solid state. The relative sizes of the ions are such that they are able to form mixed crystals in all proportions. For example, radium sulfate and barium sulfate are isomorphous because radium ions may be substituted at random for barium ions (or vice versa) in the crystal lattice without disrupting the crystal. The term is frequently applied to substances in which the crystalline structures are analogous but the chemical nature and ion sizes are such that mixed crystals are not formed with all relative proportions.

isotone
One of several nuclides having the same number of neutrons in their nuclei. For example, ${}_{19}K^{39}_{20}$ and ${}_{20}Ca^{40}_{20}$ are isotones. Commonly, one of several nuclides having the same number of neutrons, but differing in the number of protons.

isotope
1. One of several nuclides having the same number of protons in their nuclei, and hence belonging to the same element, but differing in the number of neutrons and therefore in mass number *A*, or in energy content (*isomers*). For example, ${}_6C^{12}_6$, ${}_6C^{13}_7$ and ${}_6C^{14}_8$ are isotopes. Small quantitative differences in chemical properties exist between isotopes. *(See isotope separation)*
2. A synonym for isotopic tracer. *(See tracer)*
3. A radionuclide or a preparation of an element with special isotopic composition (*allobar*) as an article of commerce, so called because of the principal use of such materials as isotopic tracers.
4. In common usage, a synonym for *nuclide* (not recommended).

isotope, stable
1. An isotope of an element which is not radioactive.
2. A mixture of isotopic non-radioactive nuclides of composition different from that occurring in nature, as an article of commerce.
3. In common usage, any stable nuclide (not preferred).

isotope dilution analysis (chemistry)
A method of chemical analysis for a component of a mixture based on the

addition to the mixture of a known amount of labeled component of known specific activity, followed by isolation of a quantity of the pure component and measurement of the specific activity of that sample.

isotope effect
The effect of nuclear properties other than atomic number on the nonnuclear physical and chemical properties of nuclides, leading to differences in the properties of isotopes. The effective nuclear properties are mass, size, statistics, spin, parity, magnetic dipole moment, and electric quadrupole moment. Isotope effects are observed in such physicochemical properties as density, rate of diffusion, reaction rate, and equilibrium distribution. In general, isotope effects are relatively small for heavy elements, but may be considerable for light elements. They are utilized in the separation of isotopes. (*See isotope separation)* In atomic spectroscopy, the slight difference in wavelength for a given spectral line of one isotope as compared with another is called the **isotope shift** and is an example of an isotope effect. (Chemistry) The effect of the difference in the mass between isotopes on the rate and/or equilibria of chemical transformations.

isotope separation
The field of knowledge and practice concerned with changing the relative abundances of isotopes. *(See thermal diffusion method)*

isotope shift
(See isotope effect)

isotope structure
(See hyperfine structure)

isotope tracer
(See tracer)

isotopic abundance
The relative number of atoms of a particular isotope in a sample of an element. The **fractional isotopic abundance** is the ratio of the number of atoms of a particular isotope to the total number of atoms of the element; it is commonly expressed as a percentage. The **relative isotopic abundance** is the number of atoms of a particular isotope relative to a specified number of atoms of a specified isotope, usually relative either to (a) 100 atoms of the most abundant isotope, or (b) 1 atom of the least abundant isotope.

isotopic carrier
(See carrier)

isotopic exchange (chemistry)

1. A process whereby atoms of the same element in two different molecules or in different sites in the same molecule exchange places. Thus

$$HC^{13}N_{(g)} + C^{12}N^{-}_{(aq.)} \rightleftarrows HC^{12}N_{(g)} + C^{13}N^{-}_{(aq.)}$$

   The equilibrium in such an exchange reaction is influenced slightly by the relative masses of the two atoms which exchange and forms the basis of one of the methods of *isotope separation* and concentration.
2. The transfer of isotopically tagged species, without net chemical reaction from one chemical form or valence state of an element to another. This may come about by exchange of tagged atoms, by exchange of other atoms in the chemical complex or by transfer of electrons. Since the equilibrium constant for this reaction differs from unity the process may be used to separate isotopes by counter-current scrubbing if the two sorts of molecules are in different phases.

isotopic indicator
A synonym for isotopic tracer. (*See tracer*)

isotopic mass
An obsolete synonym for *atomic mass.*

isotopic number
A synonym for *neutron excess.*

isotopic space
A synonym for isobaric space. *(See isobaric spin quantum number)*

isotopic spin quantum number
A synonym for *isobaric spin quantum number.*

isotopic tracer
(See tracer)

isotopic variable
A synonym for *isobaric spin quantum number.*

isotron
A device for isotope separation based on the electrical sorting of ions. Ions of different mass accelerated to a given energy have different velocities. By synchronizing the field on a deflector grid to pulses in the ion source, ions of different velocities (hence different masses) may be collected.

iterated fission expectation
In a critical assembly, the value after large time of the number of fissions per generation time arising from the daughter neutrons of a given neutron. This is a specific normalization of the *importance function.*

izod test (metallurgy)
An impact test in which a standard notched specimen supported at one end as a cantilever beam is broken by the impact of a moving pendulum. The energy expended in breaking the specimen, as determined from the decrease in energy of the pendulum, is a measure of the impact strength.

J

j-j coupling
(See coupling)

jack-leg
A draw-off at or near the bottom of a process vessel designed so as to maintain a specific liquid level in the equipment by hydraulic balance.

jacket (reactor engineering)
A thin container for a fuel slug (or several slugs) to prevent escape of the fuel by the coolant. Also frequently called **can.** Aluminum is a jacket material useful in low-temperature reactors.

jet pump
A device in which a jet of high velocity fluid is used to accelerate another fluid.

K

K-25, K-27, etc.
Code names for gaseous diffusion plants at Oak Ridge, Tennessee.

K-capture, K-electron capture
The latter term is preferred. A mode of radioactive decay involving the capture of an electron from the K shell of an atom by its nucleus. (*See electron capture*)

K-particle
(See meson)

keloid (biophysics)
An overgrowth of scar tissue which sometimes follows thermal injury or other trauma to the skin.

kernel (reactor theory)
A function of two sets of variables used to define an integral operator. If the integral operator so defined is the inverse of a differential operator, the kernel is known as the **Green's function** belonging to the differential operator. **Diffusion kernel** or **Yukawa kernel,** a Green's function of the elementary diffusion equation; **slowing-down kernel,** the probability that a neutron will go from one position to another while slowing down through a specified energy range. A **displacement kernel** is a function in which the spatial dependence is only on the distance between the two points.

kev
The symbol for 1 kilo-electron-volt, or 10^3 ev.

kick sorter
(See pulse-height analyzer)

kilocurie, Kc
One thousand *curies.*

kilo-electron-volt, kev
One thousand electron volts.

K/L ratio
The ratio of the number of internal conversion electrons from the K shell to the number of internal conversion electrons from the L shell, emitted in the de-excitation of a nucleus. This is equal to α_K/α_L where α_K is the K-electron conversion ratio, and α_L the L-electron conversion ratio. (*See conversion ratio; L/M ratio*)

Klein-Nishina formula
A formula that expresses the *cross section* of an unbound electron for scattering of a photon in the *Compton effect* as a function of the energy of the photon. The term usually refers to the **integral Klein-Nishina formula,** which gives the total cross section for the process. The **differential Klein-Nishina formula** gives the differential cross section for scattering at a given angle.

knocked-on-atom
An atom of solid which recoils after collision with an energetic particle such as a neutron, fission fragment, ion or atom moving through the solid.

The knocked-on-atom may be displaced from its lattice position and may possess sufficient energy to displace other atoms.

knocking-out effect
(See discomposition effect)

Knoop hardness
(See hardness)

Knudsen flow (free molecule diffusion)
Flow of a gas through a long tube at pressures such that the mean free path is much greater than the tube radius.

Kurie plot
A graph of a beta particle spectrum in which the quantity

$$[P(p)/p^2 F(Z,E)]^{1/2}$$

is plotted as a function of the kinetic energy E of the beta particle; p is the momentum of the beta particle and $P(p)\,dp$ is the probability that the momentum is in dp about p, and $F(Z,E)$ is the Coulomb correction factor. For *allowed transitions* and some *forbidden transitions*, these plots are straight lines. The Kurie plot is useful in determining the character of the beta transition and also in determining the maximum energy; the latter is given by the energy intercept.

L

L-capture
A synonym for *L-electron capture*, the latter term being preferred.

L-electron capture
A mode of radioactive decay involving the capture of an electron from the L shell of an atom by its nucleus. Capture from the different subshells L_I, L_{II} and L_{III} may be distinguished.

labeled compound
A compound containing radioactive atoms. By observations of radioactivity or isotopic composition this compound or its fragments may be followed through physical, chemical, or biological processes.

labeled molecule
A molecule containing one or more atoms distinguished by non-natural isotopic composition (with radioactive or stable isotopes).

labile (adj.)
A synonym for *unstable.*

laboratory system
A *frame of reference* that is attached to the observer's laboratory and hence usually is at rest relative to the surface of the earth. In nuclear physics, greater simplicity and generality are often obtained by transforming from coordinates referred to a laboratory system to those referred to a *center-of-mass system.*

laminagraphy (radiobiology)
A method of making a radiograph to show structures at one particular level within the body or object. During the exposure the film holder and the x-ray tube are shifted in relation to the subject, but the film and the tube target remain on a common axis pivoted at some point or plane in the subject. The motion is in opposite directions on parallel planes; it may be rectilinear or along various curves. The result in any case is that only the plane containing the center of motion produces a well-defined image. (Also, planigraphy, tomography, body-section radiography.)

laminar boundary layer
That portion of the boundary layer in fluid flow in which the motion approximates *steamline flow.*

laminar flow
(See streamline flow)

lanthanide contraction
The decreasing sequence of crystal radii of the tripositive rare-earth ions with increasing atomic number in the group lanthanum through lutecium.

lanthanides
The rare-earth elements from atomic numbers 58 to 71 inclusive. They have chemical properties similar to lanthanum.

Laplacian (reactor theory)
Aside from its ordinary mathematical meaning, this term has been used in place of the negative of buckling.

latent period (radiology)
Interval between irradiation and appearance of the effect in question.

latent tissue injury (radiology)
Injury which does not become manifest until some time after irradiation, and possibly until some other trauma has supervened. This second injury may be so slight that it would not, of itself, produce observable damage.

lattice
In a nuclear reactor, a structure of discrete bodies of fissionable material and non-fissionable material (especially moderator) arranged according to a regular geometrical pattern. Most heterogeneous reactors have a regular lattice structure, but this is not necessarily the case.

lattice parameter, lattice spacing (metallurgy)
The lengths of the edges of the unit cell in a crystal. The unit cell is one of the prisms created by the network of lines drawn through the points of a space lattice.

Lauritsen electroscope (instrumentation)
A rugged yet sensitive electroscope employing a metallized quartz fiber as the sensitive element.

LD 50
(See dose, median lethal)

LD 50 time
(See median lethal time)

lead (Pb)
An element, atomic number 82, atomic weight 207.21. It is used extensively as a shielding material in nuclear work because of its relative cheapness, high density and nuclear properties. The naturally occurring stable element consists of four isotopes as follows: Pb^{204}, 1.5%; Pb^{206}, 23.6%; Pb^{207}, 22.6%; Pb^{208}, 52.3%. Pb^{204} is not known to be the end product of any radioactive decay series, hence the amount of this isotope found in the lead in a uranium or thorium bearing mineral measures the "common" lead content thereof. Since all rocks carry some uranium and thorium the "common" lead of the ore minerals carries a small extra percentage of its total Pb^{206}, Pb^{207} and Pb^{208} because of these radioactive decay processes, the amount increasing with time. Its high atomic number and density make it an excellent shielding material for gamma radiation in reactors but its use for such purposes is limited by high cost and comparative scarcity.

lead age
(See age)

lead equivalent (radiobiology)
The thickness of lead affording the same reduction in radiation dose rate under specified conditions as the material in question.

leakage (reactor engineering)
1. Loss of neutrons by outward diffusion from the core of a reactor. When there is a reflector, leakage refers to net loss of neutrons that leave the core and are not reflected back into it. The **leakage spectrum** is the energy distribution of neutrons leaving the reactor.
2. Escape of neutrons or radiation through a shield, especially by way of holes or cracks through the shield.

lepton
A particle of small mass; specifically, an electron, a positron, or a neutrino (or antineutrino).

lethal mutation
(See mutation, lethal)

lethargy
The lethargy of a neutron is, to within an additive constant, the

negative of the natural logarithm of the energy of the neutron.

leucocyte (biology)
A white blood corpuscle.

leucocytosis (biology)
An increase in the number of leucocytes in the blood.

leukemia (biology)
A disease in which there is a great overproduction of immature white cells, usually with increase of the total number of circulating cells. The course of the disease is variable, at times chronic, at times, notably in children, acute. It is always fatal, although its progress can sometimes be delayed by radiation or by chemical agents. It can be produced in some animals by ionizing radiation.

leukopenia (biology)
Diminution in the number of white cells in the blood.

level width (nuclear physics)
A measure of the spread in excitation energy of an unstable state of a quantized system. As is indicated by the intrinsic *line widths* of emission or absorption lines, some energy levels in atomic and nuclear systems are found to be broad, others narrow. In nuclear physics, the phenomenon of level width has been observed and studied mostly in connection with neutron and charged-particle resonances, which are found to have nonuniform breadths in energy. If a system in a given level has several alternate modes of disintegration, there is associated with each a **partial width** proportional to the probability of disintegration by that mode; the **total level width** is the sum of the partial level widths. The level width Γ is connected with the *mean life* of the level by indeterminancy principle; thus $\Gamma = \hbar/_{\tau}$. In Be^8, for example, there is a very broad level centered at about 2.8 Mev above the ground state; a Be^8 nucleus formed in this level promptly divides into two alpha particles. The mean life is small ($\sim 10^{-21}$ sec), and the level width is correspondingly large ($\sim$0.8 Mev). Conversely, the narrowness of many slow neutron resonance peaks has led to the concept of a relatively long-lived compound nucleus. (*See Breit-Wigner formula*) Level widths usually reveal themselves as the widths of resonance peaks observed when the cross section for the particular reaction is plotted as a function of the energy of the incident particle; quantitatively, the level width is then usually taken as the full width at half maximum of such a resonance peak.

lifetime
The mean time between appearance and disappearance (birth and death) of a particle. Thus the lifetime of a thermal neutron is the mean interval between the time when the neutron becomes thermal and when it disappears from the reactor by absorption or leakage. For a homogeneous medium the **infinite** and **finite** lifetimes refer to the lifetime in infinite- and given finite-sized regions of the medium. Also a synonym for *mean life.*

limited proportionality
(See region of limited proportionality)

Lindemann electrometer (instrumentation)
A type of electrometer employing a metallized quartz fiber mounted on and perpendicular to a quartz torsion fiber in such a way that the former fiber is positioned in a system of electrodes.

line spectrum
(See spectrum)

line width
A measure of the spread in wavelength (or energy) of radiation that normally is characterized by a single wavelength (or energy value). The width is usually measured at half the maximum intensity of the line. (*See spectrum; level width; Doppler broadening*))

linear absorption coefficient
(See absorption coefficient)

linear accelerator (instrumentation)
A device for accelerating particles employing alternate electrodes and gaps arranged in a straight line, so proportioned that when their potentials are varied in the proper amplitudes and frequency, particles passing through them receive successive increments of energy.

linear amplifier (instrumentation)
A pulse amplifier in which the output pulse height is proportional to an input pulse height for a given pulse shape up to a point at which the amplifier overloads.

linear range
(See range)

linear stopping power
(See stopping power)

liquid-drop model of nucleus
A model in which the atomic nucleus is imagined to behave much like a drop of liquid. It is useful in explaining many general features of atomic masses and nuclear reactions. The nucleons within the drop are assumed to be distributed uniformly and to be in a constant state of motion similar to the thermal motion of the molecules of a liquid. Each nucleon in the interior has approximately the same binding energy, analogous to heat of condensation. The nucleons that are near the surface are less strongly bound, giving an effect similar to that of a surface tension. When a nucleus is highly excited, as by a collision, the extra energy is rapidly distributed among all of the nucleons, the effect here being similar to a rise in temperature. Particles are able to leave the nucleus only relatively slowly, since escape depends upon an accidental concentration of energy in one particle; thus *spallation* resembles the evaporation of a liquid. It is also assumed that the nucleus can vibrate as a whole, and that the effect of the electric charge is similar to that on a liquid drop; on this basis a fairly good explanation of nuclear fission is possible.

liquid-liquid extraction (chemical engineering)
A process in which two immiscible liquids are brought into contact to effect a redistribution of solutes between them.

L/M ratio
The ratio of the number of internal conversion electrons from the L shell to the number from the M shell, emitted in the de-excitation of a nucleus. (*See K/L ratio*)

LMTD (logarithmic mean temperature difference)
The logarithmic mean of the terminal temperature differences in heat exchange.

loading machine (reactor engineering)
A machine for introducing fuel into a nuclear reactor. Since the same machine commonly will remove fuel also, it may be called an *unloading machine*. The same device may perform other functions, such as handling fertile materials or uncoupled control rods, changing the pile arrangement when this is possible, and the like.

loading point
In two phase countercurrent flow in a column the flow rate below the flooding point at which either phase begins to seriously impede the flow of the other. Entrainment and pressure drop increase unduly rapidly above this point.

logarithmic amplifier
An amplifier whose output signal is a logarithmic function of the input signal.

logarithmic energy decrement, ξ
The mean value of the increase in lethargy per collision.

long-range alpha particles
(See spectrum)

low-flux reactor
A nuclear reactor having a relatively low neutron flux. *(See nuclear reactor)*

low-pressure cloud chamber (instrumentation)
A cloud chamber in which the gas is maintained at low pressure to increase the range or decrease the scattering of particle tracks.

low-temperature reactor
A nuclear reactor designed to operate at relatively low temperature. *(See nuclear reactor)*

L-S coupling
(See coupling)

lymph (biology)
An almost colorless fluid circulating in the lymphatic vessels of vertebrates. It closely resembles blood plasma in composition, and contains lymphocytes.

lymph node (biology)
Organ of lymphocyte formation with a connective tissue framework and crowded with lymphocytes. It is surrounded with a fibrous capsule and is provided with incoming and outgoing lymph vessels and a plexus of internal lymph spaces.

lymphocyte (biology)
A type of leucocyte characterized by a single sharply defined nucleus and scanty cytoplasm. Small lymphocytes constitute about 25 per cent of the white corpuscles of the circulating blood in adult men.

lymphopenia (biology)
Decrease in the number of lymphocytes in the blood.

M

macroscopic cross section

1. Cross section per unit volume (preferred).
2. Cross section per unit mass or weight.

magic numbers
One of a group of integers corresponding to the observation that a nuclide having an atomic number or neutron number equal to one of these integers has greater-than-average stability and also may possess other exceptional properties. Some of the so-called magic numbers are 2, 8, 20, 28, 50, 82, and 126. *(See nucleus, shell structure of)*

magnetic lens
An arrangement of coils, electromagnets, or magnets so disposed that the resulting magnetic fields produce a focusing force on a beam of charged particles.

magnetic moment (atomic and nuclear physics)
As applied to an atomic or nuclear particle or system of particles, the term usually refers to the **magnetic dipole moment** μ. If a particle or system is in a magnetic field of strength H, and the component of μ in the direction of the field is μ_H, the interaction energy is $-\mu_H H$. A magnetic moment is associated with the intrinsic spin of a particle, and with the orbital motion of a particle in a system. Nuclei with zero spin have no magnetic moments; those with finite spins have finite magnetic moments of magnitudes between about −2 and +6 nuclear *Bohr magnetons.*

magnetic resonance accelerator
(See cyclotron)

magnetic rigidity, Hρ
A measure of the momentum of a particle equal to the product of the magnetic intensity perpendicular to the path of the particle and the resultant radius of curvature of the path of the particle.

magneton
(See Bohr magneton)

malignant tumor
(See neoplasm)

mamu
The symbol for *millimass unit*, or 10^{-3} amu.

marrow (biology)
Soft tissue which fills the cavity in most bones.

mass absorption coefficient
(See absorption coefficient)

mass conversion factor
(See atomic weight)

mass defect
The difference between the *atomic mass* and the *mass number A* of a nuclide. For all known nuclides its absolute value is less than 0.1 amu. *(See packing fraction)*

mass-energy equivalence
The equivalence of a quantity of mass m and a quantity of energy E, the two quantities being related by the **mass-energy relation,** $E = mc^2$. This relation was proposed by Einstein as a consequence of his re-

stricted (or special) theory of relativity; it has subsequently received abundant experimental confirmation and is regarded as a general law. The factor c^2 may be regarded as the conversion factor relating units of energy and mass; various useful forms of this factor are:
$c^2 = (2.998 \times 10^{-10}$ cm $\sec^{-1})^2 =$ 8.987×10^{20} erg $\text{gm}^{-1} = 931.1$ Mev amu^{-1}. *(See relativity)*

mass-energy relation

The name sometimes given to the equation $E = mc^2$. *(See mass-energy equivalence)*

mass formula

An equation giving the *atomic mass* of a nuclide as a function of its atomic number and mass number. *(See empirical mass formula; semi-empirical mass formula)*

mass number, A

The total number of nucleons (protons and neutrons) in the nucleus of an atom or nuclide. It is given by the integer nearest in value to the *atomic mass* when the latter is expressed in *atomic mass units.* According to present theory, the mass number represents the total number of nucleons in the nucleus and hence is equal to the sum of the *atomic number* and the *neutron number.* In the symbol for a nuclide, the mass number is usually shown as a superscript following the element symbol; thus, in U^{235}, A is 235.

mass range

(See range)

mass separation

Adjusting the spacing between two or more bodies of fissionable material or parts of the core of a nuclear reactor to control the rate of fission taking place in them. If several such bodies or parts of a core are subcritical individually, but constitute a supercritical whole when assembled in close proximity, the reactor will be critical for some intermediate separation; and by adjustment of the separation the reaction rate may be held close to a constant value.

mass spectrograph

A device for analyzing a substance in terms of the ratios of mass to charge of its components. The term is usually restricted to devices which produce a focused mass spectrum of lines on a photographic plate. *(See mass spectrometer)*

mass spectrometer

A device similar to the mass spectrograph but so designed that the beam constituents of a given mass-to-charge ratio are focused on an electrode and detected or measured electrically.

mass spectrum

(See spectrum)

mass stopping power

(See stopping power)

mass transfer coefficient

The rate of transfer of mass across unit area of phase contact under unit driving force.

mass velocity

Mass rate of flow per unit cross-sectional area.

material economy (reactor engineering)

The efficiency with which material, in particular fissionable or fertile material, is used. The term may be applied to use in the reactor or in processing or reprocessing plants or to the entire series of operations.

material inventory (reactor engineering)

The quantities present of different materials—in particular, of fissionable and fertile materials. The term may represent the inventory of materials present in a reactor, in a processing or reprocessing plant, or in the entire series of establishments.

matrix element

The matrix element, B_{ij}, of a physical quantity between two states with wave functions ψ_i and ψ_j is defined by

$$B_{ij} = \int \psi_i^* B \psi_j \, d\tau,$$

where B is the operator corresponding to the physical quantity and the integration is performed over all the coordinates. If ψ_i and ψ_j are the i'th and j'th eigenfunctions of a quantity A, then B_{ij} can be considered as the ij-element of the matrix

$$\begin{matrix} B_{11} & B_{12} & B_{13} \cdots \\ B_{21} & B_{22} & B_{23} \cdots \\ B_{31} & B_{32} & B_{33} \cdots \\ \vdots & \vdots & \vdots \;\; \cdots, \end{matrix}$$

which can then be called the matrix of B in the A representation.

maximum range

(See range)

maxwellian distribution

The velocity distribution, as computed in the kinetic theory of gases, of the molecules of a gas in thermal equilibrium. It is often assumed to hold for neutrons in thermal equilibrium with the moderator (thermal neutrons).

mean free path

1. The average distance l that a particle travels between successive collisions with the other particles of an ensemble. The expression for computing the mean free path differs for different types of collisions. Thus, for a particle moving with high velocity through an ensemble of identical particles that have random positions and very small velocities, $l = 1/n\sigma$, where n is the number of particles per unit volume, and σ is the effective cross-sectional area for collision. For an ensemble of identical particles having a **maxwellian** distribution of velocities, $l = 1/\sqrt{2}\, n\sigma$.
2. By extension, one may speak of the mean free path for absorption, mean free path for inelastic collisions, or mean free path for any other kind of particle encounter. In each case, $l = 1/n\sigma$, where σ is the cross section for the specified process under consideration.
3. For any process, the reciprocal of the cross section per unit volume for that process. The **total mean free path** is the mean distance traveled by a particle between collisions.

mean free path for ionization

The average distance an ionizing particle travels in a given medium between successive ionizing collisions.

mean life, τ

The average time τ during which an atom or other system exists in a particular form. Examples are the mean life of mesons before undergoing transformation, of diffusing neutrons before being captured, of excited nuclei or atoms before losing their energy of excitation, and of atoms of a radionuclide before undergoing radioactive transformation. For a radionuclide, the mean life τ is the reciprocal of the disintegration constant λ. For *branching* decay, it is given by

$$\tau = \frac{1}{\lambda} = \frac{1}{\lambda_1 + \lambda_2 + \lambda_3 + \ldots},$$

where λ_1, λ_2, λ_3,... are the partial *disintegration constants* for the various modes involved.

mean range

(See range)

mechanical register (counting)

An electromechanical device for recording or registering counts.

median lethal dose (LD 50)
(See dose, median lethal)

median lethal time (MLT) (radiobiology)
Time required, following administration of a specified dose of radiation, for death of 50 per cent of the individuals in a large group of animals or organisms. *(See dose, median lethal)*

mega-electron volt
A synonym for *million electron volt.*

meiosis (biology)
A process involving two unique, successive nuclear divisions in which the members of each pair of chromosomes separate and form different nuclei thus reducing the number of chromosomes by half. In animals it is part of the maturation of the germ cell.

meson
Any particle having a rest mass intermediate in value between the mass m_e of an electron and that of a proton. All of the known mesons are unstable. The **mu meson** and the **pi meson** are commonly referred to as **light mesons**. Other unstable particles of rest mass about 965 m_e are called **heavy mesons** or **K-particles**. A variety of different modes of decay of heavy mesons has been observed as shown in Table I. At

TABLE I

Some properties and modes of decay of mesons and hyperons (April 1956)

Particle*	Mass in m_e	Decay products	Mean life (sec)
Mesons			
$\mu^{\pm}$	206.9 ± 0.2	$e^{\pm} + 2\nu$	2.2×10^{-6}
$\pi^{\pm}$	273 ± 0.5	$\mu^{\pm} + \nu$	2.5×10^{-8}
π^0	264.2 ± 0.5	$\gamma + \gamma$	$10^{-15} - 10^{-14}$
$\tau^{\pm}$	965 ± 2	$\pi^{\pm} + \pi^{+} + \pi^{-}$ $\pi^{\pm} + 2\pi^0$	$\sim 10^{-8}$
$\kappa^{\pm}_{\mu_2}$	966 ± 2	$\pi^{\pm} + \nu$	$\sim 10^{-8}$
$\kappa^{\pm}_{\pi_2}$	966 ± 2	$\pi^{\pm} + \pi^0$	$\sim 10^{-8}$
$\kappa^{\pm}_{\mu_3}$	967 ± 5	$\mu^{\pm} + \nu + \pi^0$ (?)	
$\kappa^{\pm}_{e_3}$	963 ± 10	$e^{\pm} + 2\nu$ (?)	
θ^0	966 ± 10	$\pi^{+} + \pi^{-}$ $\pi^0 + \pi^0$ (?)	1.3×10^{-10}
"Anomalous θ^0"	~ 1000	$\pi + \mu^{\pm} + \nu$ (?)	$> 10^{-10}$
Hyperons			
Λ^0	2181 ± 2	$p + \pi^{-}$ $n + \pi^0$ (?)	3.7×10^{-10}
Σ^{+}	2327.4 ± 1	$n + \pi^{+}$ $p + \pi^0$	$10^{-10} - 10^{-11}$
Σ^{-}	2346 ± 22	$n + \pi^{-}$	
Ξ^{-}	2581 ± 10	$\Lambda^0 + \pi^{-}$	$> 10^{-10}$

(?) indicates decay scheme not firmly established.

* With respect to the *heavy mesons* (mass ~ 965 m_e) it is not clear at present in just how many cases these represent distinct particles or merely alternate modes of decay of the same particle.

present it is not clear in just how many cases these represent the decay of different varieties of heavy mesons or merely alternate modes of decay of the same particle. Present indications are that at least two distinguishable varieties of heavy mesons exist which have equal or nearly equal rest masses. Mesons are currently denoted by lower case Greek letters. *(See hyperon)*

meson theory of nuclear forces
(See nuclear forces)

mesothorium-I ($MsTh_1$)
The common name for 6.7*y* Ra^{228}, a member of the *thorium series.*

mesothorium-II ($MsTh_2$)
The common name for 6.13*h* Ac^{228}, a member of the *thorium series.*

mesotron
An obsolete synonym for *meson* that, at the time of its use, referred predominantly to the particle now called the mu *meson.*

message register
(See mechanical register)

metal-ceramic
Substance consisting of mixture of a metal in a ceramic such as metallic oxide, carbide, or nitride, which in general gives some ductility to the ceramic. Also called **cermet.**

metal inventory
Same as *material inventory,* referring specifically to metals and, in particular, to fissionable and fertile materials.

metallography
The science which deals with the constitution and structure of metals and alloys.

metaphase (biology)
A stage in nuclear division in which the divided chromosomes lie in a plane at right angles to the division spindle, and midway between its poles.

metastable (adj.) (of a state of a system)
Capable of undergoing a quantum transition to a state of lower energy, but having a relatively long lifetime as compared with the most rapid quantum transitions of similar systems. A **metastable state** is an *excited* state from which all possible quantum transitions to lower states are *forbidden transitions* according to the appropriate selection rules. *(See selection rules)* In nuclei, metastability is the cause of nuclear isomerism. At the present time, the term metastable is applied only to those excited nuclear states having lifetimes that are measurable, that is, exceeding 10^{-20} to 10^{-9} sec. *(See isomer, nuclear)*

metastable equilibrium
A condition of pseudoequilibrium in which the free energy of a system is at a minimum with respect to infinitesimal changes, but not with respect to major changes. Although a condition of greater thermodynamic stability exists, the system may remain in the metastable state because the transition to the more stable condition is extremely sluggish.

metastasis (biology)
Growth in the body of malignant neoplastic cells at a distance from the original or parent cancer.

Mev
The symbol for 1 *million electron volts*, or 10^6 ev.

microcurie, μc
One millionth of a *curie.*

microradiography
Method of enlarging *radiographs* for examination of minute structures.

microscopic cross section
Cross section per atom or molecule.

microwave spectrum
That portion of the spectrum of a molecule having wavelengths in the region between 100 centimeters and .025 centimeters.

migration area
The migration area of a medium is one-sixth the mean square distance that a neutron travels from its birth in fission until its absorption. The medium is assumed to be of infinite extent. In Fermi age theory of thermal reactors, the migration area is the sum of the age and the square of the thermal diffusion length. In multigroup theories of thermal reactors, the migration area is the sum of the squares of the diffusion lengths for the various groups.

migration length
The square root of the migration area.

millicurie, mc
One-thousandth of a *curie*.

millimass unit, mamu
One thousandth of an *atomic mass unit*.

million electron volt, Mev
A common unit of energy in nuclear science, equivalent to 10^6 ev.

milliroentgen
One-thousandth of a *roentgen*.

minimum ionization
The smallest possible value of the *specific ionization* that a charged particle can produce in passing through a particular substance. It occurs for particles of velocity 0.95 c, which corresponds to a kinetic energy of about 1 Mev for an electron, of about 300 Mev for a pi meson, of about 2 Bev for a proton, and of about 8 Bev for an alpha particle. If the specific ionization produced along the path of the charged particle is plotted as a function of the particle energy, minimum ionization reveals itself as a broad dip, bounded on one side by a rather sharp rise for decreasing particle energy, and on the other by a gradual rise for increasing particle energy. As compared with this curve, the curve for *stopping power* versus particle energy has about the same shape up to the point of minimum ionization, but then rises more rapidly with increasing particle energy because of the occurrence of additional energy loss by *bremsstrahlung*. For singly charged particles in ordinary air, the minimum ionization is about 50 ion pairs per centimeter of path. In general, it is proportional to the density of the medium and to the square of the charge of the particle.

minimum reflux ratio
(See reflux ratio, minimum)

mirror nuclei
Pairs of nuclei, each member of which would be transformed into the other by exchanging all neutrons for protons and vice versa. Examples are ${}_3\mathrm{Li}_5^8$ and ${}_5\mathrm{B}_3^8$; ${}_{17}\mathrm{Cl}_{20}^{37}$ and ${}_{20}\mathrm{Ca}_{17}^{37}$ The most important class comprises pairs of odd-mass-number isobars for which the atomic number and the neutron number differ by one, for example: ${}_1\mathrm{H}_2^3$ and ${}_2\mathrm{He}_1^3$; ${}_{14}\mathrm{Si}_{15}^{29}$ and ${}_{15}\mathrm{P}_{14}^{29}$.

mitosis (biology)
A form of nuclear division in which the daughter nuclei come to have the same number and kinds of chromosomes as the parent nucleus, characteristic of most divisions other than those involving meiosis.

mixing (isotopes separation)
In separation by gaseous diffusion through barriers, the process, dif-

fusion, turbulent convection, or other, whereby the concentration gradient of the lighter isotope normal to the diffusion barrier is kept as small as possible.

mixing efficiency (isotopes separation)
A measure of the effectiveness of the mixing process in terms of the effective simple process factor and the factor which would obtain under conditions of perfect mixing.

M/N ratio
1. (Radiation chemistry) The *ion yield.*
2. (Nuclear physics) A ratio of conversion fractions for the M and N shells analogous to the *K/L ratio*.

mobility (ion)
The average drift velocity imparted to a charged particle by a unit potential gradient.

moderation
The slowing down of a particle, usually a neutron, as a result of collisions with nuclei.

moderator
Material used in a nuclear reactor to moderate, i.e., slow down, neutrons from the high energies at which they are released. *(See nuclear reactor)* Neutrons lose energy by scattering collisions with nuclei of the moderator. A good moderator has high scattering cross section and low atomic weight. In each collision there is a chance of absorption. To reduce this loss of neutrons during the slowing-down process, the moderator atoms also should have low-neutron absorption cross section. High scattering cross section implies frequent collisions; these give the neutron a better chance of being slowed down before it is captured and also reduce the average net distance traveled in slowing down so that leakage is reduced. Small mass results in a large average energy loss per collision (requiring few collisions) and so reduces both opportunities for capture and distance traveled. Some practical materials are carbon (used in the form of graphite), beryllium and its compounds, and water. Heavy water *(see water)* is preferable to light in some cases because, although its heavier hydrogen atoms reduce the neutron energy less per collision than those of light hydrogen, they have lower neutron-absorption cross section. Paraffin and other hydrocarbons, although made up of good moderating atoms are not used as moderators except in laboratory experiments because of their chemical instability under reactor conditions of intense radiation.

moderator control
Control of a nuclear reactor by adjustment of the position or quantity of the moderator in such a way as to change the fraction of neutrons so that, before leaking out or being captured, they are slowed to speeds at which they can excite fission in the fuel used.

modulus of elasticity
The ratio of stress to strain within the elastic range. When the modulus of elasticity is determined from the slope of the stress-strain curve in a tension or compression test, it is often called **Young's modulus.** Young's modulus for steels is approximately 30,000,000 lb per sq in., for copper alloys about 15,000,000 lb per sq in., and for aluminum alloys about 10,000,000 lb per sq in. The modulus of elasticity in shear is termed the **modulus of rigidity.** It is measured in a torsion test, and is the ratio of the unit shear stress to the displacement which it produces per

unit specimen length in the elastic range. For metals, the shear modulus is approximately 0.4 the modulus of elasticity in tension.

modulus of rigidity
(See modulus of elasticity)

modulus of rupture (metallurgy)
A measure of the ultimate strength or the breaking load per unit area of a specimen as determined from a torsion, or more commonly from a bending, test. The modulus is calculated from the breaking load assuming that the specimen remains elastic until rupture occurs, although this may be not the case. Its value will be intermediate between the ultimate tensile and compressive strengths.

mole fraction (isotopes separation)
The number of atoms of a certain isotope of an element expressed as a fraction of the total number of atoms of that element present in the isotopic mixture.

molecular beam
A unidirectional stream of neutral molecules passing through a vacuum, usually with thermal velocity. The source may be simply a pinhole in a box containing gas or vapor under low pressure. A system of slits typically serves to define the beam. Measurement of the transmission of the beam through appropriate magnetic and electric fields can yield accurate values for quantities such as nuclear magnetic moments. *(See nuclear magnetic resonance)*

molecular distillation
An isotope separation process in which molecules are evaporated from a surface at extremely low pressures and are condensed before undergoing collisions.

molecular stopping power
(See stopping power)

monazite
A mineral, phosphate of cerium metals, essentially (Co, La, Nd, Pr) PO_4, usually containing thorium also as $Th_3(PO_4)_4$. It is the most important source of thorium and occurs principally in sand or gravel deposits.

monitor
An instrument to measure continuously or at intervals a condition that must be kept within prescribed limits, e.g., radioactivity in the coolant of a reactor or radiation levels in the working areas of the building. Also used as a verb.

monitor ionization chamber

1. An ionization chamber mounted in an x-ray beam and connected to a continuously reading instrument to serve as an indicator of constancy of x-ray output.
2. An ionization chamber used to detect the presence of undesirable radiation in connection with health protection.

monitoring (radiobiology)
Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, or in a person, as a safety measure for purposes of health protection. **area monitoring** Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room or equipment. Usage in some laboratories or operations distinguishes between routine monitoring and survey activities. **personnel monitoring** Monitoring any part of an individual, his breath, or excretions, or any part of his clothing. *(See also protection survey)*

monochromatic radiation
(See radiation, monochromatic)

monoenergetic radiation
(See radiation, monoenergetic)

Monte-Carlo method
A method of solution of a group of physical problems by means of a series of statistical experiments which are performed by applying mathematical operations to random numbers.

Mott scattering formula
The formula giving the differential cross section for the scattering of identical particles due to a Coulomb interaction. *(See Coulomb force)*

MTD (mean temperature difference)
The average temperature difference acting to cause heat exchange.

mu meson
(See meson)

mucosa (biology)
Mucous membrane lining gastrointestinal tract, air passages, urogenital tract, lachrymal sac and conjunctiva.

multi-group model
A model in which the neutron flux is divided into parts corresponding to several discrete energy ranges. Account is taken of the difference in spatial behavior of the different energy groups and also of transfer of neutrons between the various energy groups.

multiple decay, multiple disintegration
Synonyms for *branching*.

multiple effect evaporator (chemical engineering)
A series of evaporators so connected for heat economy that the overhead vapor from the first serves as the heating medium for the next. Each successive evaporator operates at a pressure lower than that preceding it to maintain a temperature difference between the heating vapor and the boiling liquid.

multiple scattering
(See scattering)

multiplication
The ratio of neutron flux in a subcritical reactor to that supplied by a neutron source. It is the factor by which, in effect, the reactor multiplies the source strength and is equal to $1/(1-e^{-k EFF})$. This factor is measured frequently in the performance of a critical experiment or in the first start-up of a virgin reactor. *(See neutron source)*

multiplication constant, k
The ratio of the number of neutrons present in a reactor at a given time to the number present one finite lifetime earlier. Sometimes called the effective multiplication constant. For a homogeneous medium the **infinite (k)** multiplication constant refers to the multiplication constants in an infinite medium. The multiplication constant minus one is called the excess multiplication constant. *(See reactivity)*

multipole moments
The electric and magnetic multipole moments of a system in a given state ψ are measures of the charge, current, and magnet (via intrinsic spin) distributions in the state ψ, and determine the interaction of the system with weak external fields. In contrast with these **static multipole moments,** there are also **transition multipole moments,** which determine radiative transitions between two states and therefore depend on both states. (*See radiation, multipole*) Both kinds of multipole moments may be written as

$$Q_{l,m} = \int_{r}^{l} Y_{lm}^{*} \ (\theta,\phi)\rho(r)dV$$

for the electric multipole moment of order l, m, and

$$M_{l,m} = -\int_{\tau}^{l} Y_{lm}^{*}(\theta,\phi)\,\rho\,\mathrm{div}\,M(r)\,dV$$

for the magnetic multipole moment of order l,m. In these formulas the function $Y_{lm}(\theta,\phi)$ is the normalized lm spherical harmonic, depending on ϕ as $e^{im\phi}$; $\rho(r)$ is the proper charge density; and $M(r)$ is the proper density of magnetization arising from moving charges and from intrinsic spin moments. The difference between static and transition moments is in the densities ρ and μ; for example, $\rho = e\sum |\psi(r)|^2$ for the static case, and $\rho = e\sum \psi_f(r)\,\psi_i(r)$ for the transition case between states i and f. The summations are over all charged particles.

multipole radiation
(See radiation, multipole)

muon
A synonym for mu *meson.*

mutant
An individual showing a mutation.

mutation, gene (biology)
A sudden and permanent change in a gene. The term mutation is sometimes used in a broader sense, to include *chromosome aberrations* as well.

mutation, lethal (biology)
Mutation leading to death of the offspring at any stage.

N

n
The symbol for a *neutron.*

n-unit, N-unit (neutron doses) (radiobiology)
The n-unit is that quantity of fast neutrons which will produce in a 100-r Victoreen r-meter the same reading as 1 roentgen of x-rays; the N-unit is the same except that the 25-r chamber is used. (Note: These are not actually proposed units, but have been employed as convenient interim methods of specifying neutron doses until satisfactory units and methods of measurement can be devised.)

NaK
Alloy of sodium (Na) and potassium (K) which in some ranges of composition is molten at room temperature and below. For this reason it has been suggested for use as a liquid-metal heat-transfer fluid.

natural radioactivity
(See radioactivity, natural)

natural-uranium reactor
A nuclear reactor in which natural (unenriched) uranium is the principal fissionable material. (*See uranium*)

necking down (metallurgy)
The localized reduction in area of a ductile tension test specimen in the region of fracture.

necrosis (biology)
Death of tissue.

needle
(See implant)

negative electron
A synonym for *electron.*

negative proton
A synonym for *anti-proton.*

negatron, β^-
A negative *electron*. The term is sometimes used when it is necessary to distinguish between positive and negative electrons. The term has not been generally adopted in this country. *(See positron)*

neoplasm (biology)
A new growth of cells which is more or less unrestrained and not governed by the limitations of normal growth. **Benign**, if there is some degree of growth restraint and no spread to distant parts. **Malignant,** if the growth invades the tissues of the host, spreads to distant parts, or both.

neptunium (Np)
An element, atomic number 93, discovered by E. M. McMillan and P. Abelson in 1940, and named after the planet Neptune. They synthesized $2.33d$ Np^{239} by the reaction

$$U^{238}\,(n,\,\gamma)U^{239}\xrightarrow[23.5m]{\beta^-}Np^{239}$$

The longest-lived isotope, $2.2\times 10^{6}y$ Np^{237} is formed in low yield in nuclear reactors by the reaction

$$U^{238}\,(n,\,2n)U^{237}\xrightarrow[6.8d]{\beta^-}Np^{237}$$

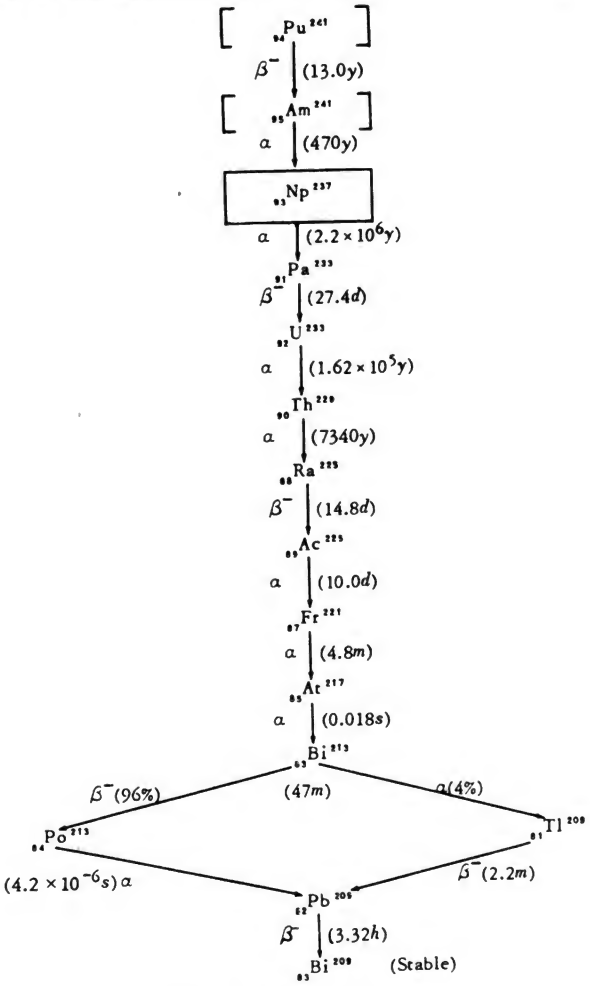

Fig. 3 The neptunium series.

Several other isotopes of shorter half-life are known. Neptunium has four oxidation states, +3, +4, +5, and +6.

neptunium series
The series of nuclides resulting from the decay of the long-lived synthetic nuclide Np^{237}. Mass numbers of all members are given by $4n + 1$, where n is an integer. The sequence is also known as the **$4n + 1$ series.** Many other synthetic nuclides decay in collateral series into this sequence. Only the stable end-product Bi^{209} occurs in nature. The sequence of decay in the neptunium series is as indicated in fig. 3.

net transport (isotopes separation)
The difference between the total rate at which desired isotopes are transmitted toward the production end of a plant through any section, and the rate at which they would be carried in the same flow by material of natural abundance.

neutrino
A neutral particle of very small (possibly zero) rest mass and of spin quantum number 1/2. The mass has been shown experimentally to be less than 0.01 m_e. The neutrino was postulated to account for the continuous energy distribution of beta particles and to conserve angular momentum in the beta-decay process. Experimental evidence is also accumulating to the effect that, for the linear momentum to be conserved in the beta process, there must be a contribution from a departing neutrino. Presumably, a neutrino (or *antineutrino*) is emitted in every beta transition. The energy of a neutrino emitted in a beta disintegration is assumed to be equal to the difference between the energy of the particular beta particle and the energy corresponding to the upper limit of the continuous spectrum for that beta transition. The neutrino has also been postulated as one of the particles in pi-meson decay and as one or two of the particles in mu-meson decay. Because of its properties, the neutrino has negligible interactions with matter and has not been detected directly. The symbol ν is often used for the neutrino. (*See antineutrino*)

neutron
A nuclear particle of zero charge and mass number 1. The mass is 1.008941 amu, its spin ½, and its magnetic moment, $\mu = -1.9125$ nuclear magnetons; statistics, Fermi-Dirac. (*See nucleon; elementary particle*) Neutrons are a constituent of all nuclei except $_1H^1$. Neutrons in varying degrees undergo capture by all known nuclides except He^4. They are unstable with respect to β^- emission to give $_1H^1$, the half-life being estimated to be between 10 and 25 minutes. Neutrons produce no detectable primary ionization in their passage through matter, but ionization is produced by products of neutron collisions (recoil nuclei, γ-rays from inelastic scattering and from neutron capture). Neutrons in a medium with kinetic energy distribution comparable with the kinetic energy distribution due to thermal agitation of the nuclei comprising the medium, are termed **thermal neutrons.** An **epithermal neutron** is a neutron having an energy in the range immediately above the thermal range, that is, having an energy between a few hundredths and 10^2 ev. Neutrons having energies in a roughly defined range that is often considered to extend from about 10^2 to 10^5 ev are **intermediate neutrons.** Thus they are more energetic than epithermal neutrons, but less energetic than **fast neutrons,** which have energies much greater than some arbitrarily lower limit. This lower limit is often only a few kilovolts, sometimes exceeding 0.1 Mev. For a specified nuclide or element, neutrons that have energies

in the region where the cross section of the nuclide or element is particularly large because of the occurrence of a resonance are described as **resonance neutrons.** For example, cadmium resonance neutrons have energies between 0.05 and about 0.3 ev.

neutron cycle (reactor theory)
The life history of the neutrons in a reactor starting with the fission process and continuing until all the neutrons have been absorbed or have leaked out.

neutron density
The number of neutrons per unit volume. Partial densities may be defined for neutrons characterized by such parameters as speed and direction.

neutron economy (reactor engineering)
Degree to which neutrons are used in desired ways instead of being lost by leakage or useless absorption. Desired uses of neutrons may include maintaining the chain reaction,' converting fertile to fissile material, producing other desired isotopes, and experimental uses.

neutron energy groups (reactor theory)
In the early days of neutron experiments the neutron energy was specified by a material which had strong absorption for neutrons of that energy as follows:

Name of Group	Absorber	Approximate Energy	Linear Absorption Coefficient
A	Silver	4 volts	210 cm^{-1}
B	Gold	7 volts	–
C	Cadmium	0.3 volts-thermal	130 cm^{-1}
D	Rhodium	1.0 volts	41 cm^{-1}
	Indium	1.2 – 1.50 volts	–
I	Iodine	~36 volts	–

(See Phys. Rev. 50, 899, 1936)

Currently, the parts of the neutron flux arising from the decomposition into discrete energy ranges as used in the *multi-group model*.

neutron excess, neutron excess number
The number I of neutrons in a nucleus in excess of the number of protons; that is, $I = N\text{-}Z = A\text{-}2Z$, where N is the *neutron number*. (*Syn. isotopic number*)

neutron flux
A term used to express the intensity of neutron radiation. The number of neutrons passing through a unit area in unit time. For neutrons of a given energy, the product of neutron density with speed. (*See flux*)

neutron hardening
The effect caused by the diffusion of thermal neutrons through a medium having an absorption cross section decreasing with energy. Because the slower neutrons are preferentially absorbed, the average energy of the diffusing neutrons becomes greater.

neutron inventory
(See inventory)

neutron number, N
The number of neutrons in a nucleus. It is equal to $A\text{-}Z$, the difference between the mass number and the atomic number. When it is desired to indicate explicitly the neutron number in the symbol of a nuclide, the number is added as a subscript following the element symbol; thus in ${}_{26}\text{Fe}^{59}_{33}$, N is 33.

neutron producer
A nuclear reactor designed as a source of neutrons for isotope production.

neutron source (reactor engineering)
Any material that emits neutrons, e.g., a mixture of radium and beryl-

lium. A neutron source may be introduced into a nuclear reactor as part of the start-up procedure. The use of a neutron source is a safety measure to insure having at the outset a neutron flux large enough to be distinguished from background and measured quickly. Otherwise, as control rods were withdrawn, the reactor might reach a critical condition before its flux had risen high enough for the control system to operate. Especially if the reactor had become *prompt-critical* a rapid and uncontrolled increase in power to a harmful level then might result. When such a source is used, the control instruments show at an earlier stage the approach to critical conditions as safety and control rods are withdrawn. Also used in critical experiments. Any device or arrangement which utilizes a nuclear reaction for the purpose of generating neutrons. (*See counter range; critical experiment; multiplication*)

neutron therapy (radiology)
Irradiation with neutrons for therapeutic purposes.

neutrons per absorption, η
The total number of neutrons emitted per neutron absorbed in fuel.

neutrons per fission
The total number of neutrons emitted per fission, usually including delayed neutrons.

noncentral force (nuclear)
(*See nuclear forces*)

nonlinearity (radiation instruments)
The deviation of any functional relationship from direct proportionality.

normalized
In nuclear or atomic physics, a synonym for *ground.*

normalized plateau slope (instrumentation)
A figure of merit for a counter tube. The percentage change in counting rate divided by the percentage change in voltage, using the threshold values as a base. (*See plateau characteristic*)

NTP (number of theoretical plates)
(*See theoretical stage*)

NTU (number of transfer units)
(*See HTU*)

nuclear charge
The sum of the charges of the protons in a nucleus. It is equal to $+Ze$.

nuclear chemistry
A term for the chemical aspects of nuclear science and the applications of nuclear science to chemistry. Its exact connotation is not universally agreed upon. In the more limited sense it denotes the study of the reactions of nuclei and the properties of the resulting nuclear species.

nuclear disintegration
(*See disintegration, nuclear; reaction, nuclear; radioactivity*)

nuclear emulsion
A photographic emulsion especially designed to register the track of a charged particle as a series of dark grains. Microscopic examination is necessary. The emulsion is usually prepared in the form of a layer, often supported on a glass sheet, called a nuclear plate. Various nuclear emulsions are available, having different sensitivities for different kinds and energies of particles. Such emulsions are much thicker than ordinary photographic emulsions, being from 25μ to more than 1 mm in thickness, and usually

have a much higher content of silver halide.

nuclear energy
Energy released in nuclear reactions, especially in quantities sufficient to be of interest in engineering or in astrophysics.

nuclear fission
(See fission, nuclear)

nuclear forces
Nonelectromagnetic forces between and peculiar to nucleons. Sometimes called **specifically nuclear forces** to emphasize that they do not include electrostatic and magnetic forces, even though the latter are operative in nuclei. Nuclear forces are of short range, are predominantly attractive, and are nearly, if not completely, charge independent; that is, the neutron-neutron, neutron-proton, and proton-proton specifically nuclear interactions are almost identical in character. The **meson theory of nuclear forces,** due originally to Yukawa, postulates the existence of a particle, now called a *meson,* the exchange of which between two nucleons is responsible for the force between them. These mesons may be positive, negative or neutral, and are presumed to be identical with pi mesons.

In phenomenological treatments of nuclear forces, it is usually assumed that the forces act between pairs of nucleons (the force between any pair being independent of the presence of other nucleons) and that they are derivable from (can be written as the gradient of) a velocity independent potential function. The nuclear force may be a **central force,** being a simple attraction or repulsion directed along the line joining the pair, or it may be a **noncentral,** or **tensor, force** whose direction depends in part on the spin orientation of the nucleons. It may also be an ordinary, or **Wigner force,** or an **exchange force** of the Majorana, Bartlett, or Heisenberg type. Thus

$$V = V_w(r) + V_m(r)P^m + V_b(r)P^b + V_b(r)\,P^b + V_{tw}(r)\,S_{12} + V_{tm}(r)\,S_{12}P^m,$$

where the various $V(r)$'s are functions of the distance r between the nucleons, the P's are the three types of exchange operators (P^m interchanging the space coordinates of the two nucleons, when acting on their wave function, P^b interchanging their spin coordinates, and P^h interchanging both space and spin coordinates), and S_{12} is the tensor potential given by

$$S_{12} = \frac{3(\sigma_1 \cdot r)\,(\sigma_2 \cdot r)\,(\sigma_1 \cdot \sigma_2)}{r^2}$$

where r is the separation vector, and σ_1 and σ_2 are the vector spin operators of the two nucleons.

nuclear induction
Magnetic induction in samples of solids, liquids or gases that has its origin in the magnetic moments of nuclei contained in the sample. The effect depends upon the unequal population of energy states available when the material is placed in a magnetic field. Although in general the nuclear induction is very weak, it becomes readily observable in the Bloch type of experiment which depends upon the occurrence of *nuclear magnetic resonance.*

nuclear isomer; nuclear isomerism
(See isomer, nuclear; isomerism, nuclear; isomeric transition)

nuclear magnetic resonance
The resonance phenomenon encountered in energy transfers between a radiofrequency alternating magnetic field and a nucleus placed in a constant magnetic field H that is

sufficiently strong to decouple the nuclear spine from the influence of the atomic electrons. Resonance is encountered when $\omega = gH$, where ω is the angular frequency of the alternating field and g the nuclear *gyromagnetic ratio*. Transitions can then be induced between the various possible substates corresponding to different quantized orientations of the nuclear spin relative to the direction of H. The phenomenon has found application in connection with measurements of g both by molecular beams and by the use of macroscopic samples of solids or liquids. In the latter case, ω is commonly held constant, and H is varied back and forth through the resonance value for the sake of convenience in producing a display upon an oscilloscope. (*See nuclear induction*)

nuclear magneton
(See Bohr magneton)

nuclear model
(See independent particle model of nucleus)

nuclear potential
(See potential, nuclear)

nuclear potential energy
(See potential energy, nuclear)

nuclear power
Power released in *exothermic* nuclear reactions and useful in ways comparable with, for example, electric power.

nuclear radius
(See radius, nuclear)

nuclear reaction
(See reaction, nuclear)

nuclear reactor (commonly only *reactor*)
An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. It includes fissionable material (fuel), such as uranium or plutonium, and moderating material (unless it is a fast reactor) and usually includes a reflector to conserve escaping neutrons, provision for heat removal and measuring and control elements. The terms *pile* and *reactor* have been used interchangeably, with *reactor* now becoming more common. They usually are applied only to systems in which the reaction proceeds at a controlled rate, but they also have been applied to bombs. Reactors sometimes are designated according to the moderator used (e.g., graphite or beryllium reactor), or the coolant (e.g., gas-cooled, liquid-metal cooled). A **thermal reactor** is a nuclear reactor in which fission is induced primarily by neutrons of such energy that they are in substantial thermal equilibrium with the material of the core. A representative energy for thermal neutrons often is taken as 0.025 ev (2200 meters per second) which corresponds to the most probable velocity of neutrons in a maxwellian distribution at 293°K, although most thermal reactors actually operate at a higher temperature. A *moderator* is an essential element of a thermal reactor. In an **epithermal reactor** a substantial fraction of fissions (say 30 or 40 per cent) are induced by neutrons of more than thermal energy. In an **intermediate reactor** fission is induced predominantly by neutrons whose energies are greater than thermal but much less than the energy with which neutrons are released in fission. From 0.5 to 100,000 electron volts may be taken roughly as the energy range of neutrons inducing fission in intermediate reactors. The neutron absorption resonances of the fuel may be important in this range. A **fast reactor** is a nuclear reactor in which there is

little moderation and fission is induced primarily by fast neutrons, that have lost relatively little of the energy with which they were released. The slowing down of neutrons that does occur is due largely to inelastic scattering instead of elastic scattering. About 100,000 electron volts is regarded as the minimum value of mean energy of neutrons inducing fission for a reactor to be considered fast, with 1/2 to 1/3 Mev more common. Sometimes the fission threshold of U^{238} is taken as the lower limit of the fast range. Reactors of this type have potentially high neutron economy. In a **heterogeneous reactor** the fissionable material and moderator are arranged as discrete bodies (usually according to a regular pattern) of such dimensions that a nonhomogeneous medium is presented to the neutrons. A **homogeneous reactor** is a nuclear reactor in which the fissionable material and moderator (if used) are combined in a mixture such that an effectively homogeneous medium is presented to the neutrons. Such a mixture is represented either by a solution of fuel in moderator or by discrete particles having dimensions small in comparison with the neutron mean free path. (*See fuel; moderator; reflector*)

Reactor terminology also includes: **high-flux reactor** Since a high flux results from a high rate of fission per unit volume, a high-flux reactor operates at high power density. **high-temperature reactor** Roughly, the temperature may be considered high in this connection if it is high enough to permit the generation of mechanical power at good efficiency. **power reactor** A reactor capable of providing useful mechanical power. In reactors planned at the present time, this is done by generating energy in the form of heat conveyed at a temperature high enough for reasonably efficient conversion to mechanical work. **research reactor** A reactor whose primary purpose is use as a research tool, for which it may supply neutrons, other particles, and gamma radiation. It will include special provision for exposing samples (which may include living organisms) to these fluxes and may have provision for the production of transmutation products as well as various special experimental facilities. (*See thermal column*) **thermonuclear reactor** An apparatus capable of sustaining an appreciable thermonuclear reaction. (*See reaction, thermonuclear*)

nuclear species

1. A kind of atom characterized by the charge, mass number and quantum state of its nucleus. A *nuclide.*
2. A nucleus of given charge, mass number, and quantum state. Also a collection of such nuclei.

nuclear spin
(See angular momentum)

nucleic acid (biophysics)
A group of compounds extractable from the cell nucleus and decomposable into phosphoric acid, a pentose (either ribose or desoxyribose), a purine base, and a pyrimidine base. In general, it is most highly concentrated in the nucleus but also present in a more diluted form in the cytoplasm and particular structures of the cell.

nucleogenesis
Large-scale formation of nuclei in nature. (*See ylem*)

nucleon
A constituent particle of the atomic nucleus; therefore, according to present theory, a *proton* or a *neutron.*

nucleon number
A synonym for *mass number*.

nucleonics (nuclear technology)
The applications of nuclear science in physics, astronomy, chemistry, biology, geology, industry and armaments, and the techniques associated with these applications.

nucleoprotein
Protein conjugated with nucleic acid.

nucleus
The positively charged core of an atom, with which is associated practically the whole mass of the atom, but only a minute part of its volume.

A **compound nucleus** is an *excited* nucleus formed as an intermediate stage in an induced nuclear reaction It is characterized by a lifetime long (perhaps 10^{-16} sec), compared with the normal transit times of nuclear particles across the nucleus ($\sim 10^{-22}$ sec). Thus in the reaction $N^{14} + He^4 \rightarrow F^{18*} \rightarrow F^{17} + n^1$, the F^{18*} (asterisk indicates an excited state) is a compound nucleus having the composition of F^{18}. It is believed that a great many, though not all, nuclear reactions proceed through a compound nucleus stage. (*See liquid-drop model of nucleus*; *alpha-particle model of nucleus*)

(Metallurgy) A small cluster of atoms of a new and more stable phase formed within a less stable phase as a preliminary to its conversion to the stable variety. Processes of solidification, recrystallization and many phase changes in the solid state proceed by a mechanism of nucleation of the new phase, followed by growth of the nuclei at the expense of the old phase. The nuclei are produced as a result of thermal fluctuations, and become stable as the departure from the equilibrium transition temperature increases. Solid particles of other materials, if similar in structure, may sometimes serve as nuclei. Nucleation is generally more probable at a surface, a grain boundary, or a slip line than elsewhere.

(Biology) A definitely delineated body within a cell, containing the chromosomes.

nucleus, compound or intermediate
(*See nucleus*)

nucleus, recoil
A nucleus that recoils as a result of a collision with a nuclear particle or, as in radioactivity, as the result of the ejection of a particle from it.

nucleus, shell model of
1. A nuclear model in which shell structure is postulated.
2. A nuclear model in which shell structure is a consequence of the postulates. Hence, usually, a synonym for *independent particle model of nucleus.*

nucleus, shell structure of
The arrangement of the quantum states of nucleons of a given kind in a nucleus in groups of approximately the same energy. Each such group is called a **shell**, and the number of nucleons in each shell is limited by the Pauli exclusion principle. A **closed shell** is one containing the maximum number. A nucleus having all of its nucleons of either or both kinds in closed shells possesses greater than average stability. *(See independent particle model of nucleus; magic numbers)*

nuclide
A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons Z, number of neutrons N, and energy content; or, alternatively, by the atomic number Z, mass number A $[= N + Z]$, and atomic mass. To be regarded as a distinct nuclide, the atom must be

capable of existing for a measurable lifetime (generally greater than 10^{-10} sec). Thus nuclear isomers are separate nuclides, but promptly decaying excited nuclear states and unstable intermediates in nuclear reactions are not so considered. (*See mirror nuclides; radioactivity, natural*)

nuclide, shielded
A nuclide of charge higher by one unit than a stable nuclide of the same mass number. Such a nuclide cannot be formed by negative beta decay from the normal state of a parent; hence when it appears as a fission product it is regarded with high probability as a primary fission product. (*See fission yield (independent)*)

nuclidic mass
The mass of the neutral atom of a nuclide, in amu. Also called atomic mass and, loosely, isotopic mass.

O

odd-even nuclei
Nuclei which contain an odd number of protons and an even number of neutrons. *(See nucleus)*

odd-odd nuclei
Nuclei which contain an odd number of protons and an odd number of neutrons. *(See nucleus)*

one-group model
A model for the study of neutron behavior in which neutrons of all energies are treated as having the same characteristics.

O-P process
An abbreviation for *Oppenheimer-Phillips process.*

opaque
Preventing the passage of radiation or particles (opposite of *transparent*). The term usually is qualified as to the radiation involved; e.g., cadmium is opaque (**black**) to slow neutrons. The term is likely to be relative with respect to thickness, for, especially with gamma rays which have no fixed range and are reduced approximately exponentially with distance, a thick layer of a given material may be substantially opaque to these rays but a thin one highly transparent. *(See attenuation factor)*

open-air ionization chamber
(*See ionization chamber, free air, open air*)

open cycle
Cycle of operation of a heat engine in which the power fluid is used only once and replaced with fresh fluid instead of being recirculated after its passage through the power cycle. Also applicable to a cooling system in which the coolant is used once and then discarded. *(Cf. closed cycle)*

operating line
A mathematical or graphical relation, based on material and energy balances, which relates the properties of one of two streams in contact to those of the other at the same point in the apparatus.

Oppenheimer-Phillips process
A mechanism of accomplishment of the (d,p) reaction in which the proton of the incident deuteron is thought to be repelled by the Coulomb force between it and the target nucleus, while the neutron of the incident deuteron approaches close enough to the target nucleus to have a chance of becoming bound sufficiently to overcome its rather small binding energy in the deuteron. The result is a disruption of the deuteron, with the capture of the neutron and repulsion of the proton. Complete penetration of the Coulomb barrier by the proton is not required, and therefore the effect evidences itself in the range of bombarding energies below the Coulomb barrier height, that is, commonly below 10 Mev. The effect is a special case of *stripping*.

orbit shift coils (betatron, synchrotron)
A set of coils, usually placed on the magnet pole faces in the region of the stable orbit, through which a pulse of current is passed to alter momentarily the guiding field in such a way as to cause the orbit radius to increase or decrease, or the plane of the orbit to rise, lower or tilt, thereby causing the accelerated particles to strike a target placed outside the stable orbit, or to enter a deflector for the production of an external beam.

orbital-electron capture
(See electron capture)

orientation (metallurgy)
The direction in space of the axes of a crystal, or in a polycrystalline solid, the relation between similar axes of different crystals. In an ideal isotropic solid, the crystals are arranged completely at random. When such a solid is plastically deformed, or plastically deformed and annealed, a partial rearrangement of the crystals frequently occurs so that similar axes display a common **preferred orientation.** The degree of preferred orientation depends upon the material, the type and amount of deformation, and the subsequent heat treatment. The pattern of preferred orientation is called the **texture.** Solids with preferred orientation usually possess directional properties.

ortho hydrogen
A hydrogen molecule in which the two nuclear spins are parallel, forming a triplet state, $S = 1$. *(See para hydrogen)*

osseous (biology)
Bony.

osteogenic (biology)
Bone-forming.

outer bremsstrahlung
(See bremsstrahlung)

over-all coefficient of heat transfer
The rate of heat transfer across unit area of a specified surface for unit temperature difference between two specified points.

overhead (chemical engineering)
The total vapors leaving the top of a tower or column. **Overhead product** is the distillate.

overvoltage
In a Geiger-Muller counter tube, the difference between the operating voltage and the Geiger threshold.

P

p
The symbol for a *proton.*

pack rolling (metallurgy)
The rolling of two or more metal sheets arranged in layers, or the rolling of a metal sheet while sandwiched between two other metal sheets. Pack rolling permits more accurate control of final thickness, and the production of thinner sheets of foil. It is also practiced when the ductility of the metal to be rolled is so low that fracture may result.

packed tower (chemical engineering)
A vertical column, used for distillation, absorption, extraction and the like, containing packing, e.g., Raschig rings, Berl saddles or crushed rock, which provides a large contacting area between the phases.

packing fraction
The ratio Δ/A of the *mass defect* Δ and *mass number* A of a nuclide. It is positive for most nuclides of $A < 16$ and $A > 180$, and negative for most other nuclides. Except for a few very light nuclides, its absolute value is less than 10^{-3}.

pair production
The conversion of a photon into an electron and a positron when the photon traverses a strong electric field, such as that surrounding a nucleus or an electron. The electric charge is conserved, since the electron and positron have charges of equal magnitude and opposite sign. Of the energy $h\nu$ of the photon, a part, $2m_ec^2$, is accounted for by the energy equivalent of the rest mass of the resulting *electron-positron pair.* If the electric field traversed is that of a nucleus, the quantity $2m_ec^2$ is approximately the threshold energy; the excess, $h\nu - 2m_ec^2$, then appears as the kinetic energies of the electron and positron. If the electric field traversed is that of an electron, this electron itself acquires large kinetic energy and the threshold energy is then precisely $4m_ec^2$. Pair production is one of three distinct processes by which a photon can effect the emission of an electron from matter, the other two processes being the *photoelectric effect* and the *Compton effect.* For photon energies exceeding $2m_ec^2$, the *cross section* for pair production increases with Z and with the photon energy.

pair-production absorption
The absorption of gamma rays or other photons in the process of *pair production.*

para hydrogen
A hydrogen molecule in which the two nuclear spins are anti-parallel, forming a singlet state, $S = 0$. *(See ortho hydrogen)*

parallel flow
Flow in the same direction of two or more streams within a system.

parallel plate counter chamber
A counter chamber with plane parallel electrodes.

parasitic capture
Any absorption of a neutron which does not result in either a fission or the production of a desired element.

parent (radioactive precursor)
A radionuclide that upon disintegration yields a specified nuclide, the *daughter*, either directly or as a later member of a *radioactive series*. Thus U^{238} is the parent of all members of the uranium series, including the end product, Pb^{206}.

parent peak or **parent mass peak**
That component of a mass spectrum which results from the undissociated molecule.

parity
A symmetry property of a wave function; the parity is 1 (or even) if the wave function is unchanged by an inversion (reflection in the origin) of the coordinate system, and -1 (or odd) if the wave function is changed only in sign. All nondegenerate stationary states have a definite parity.

partial condensation
(See dephlegmation)

partial wave
(See phase shift)

particle accelerator
Any device for accelerating charged particles.

partition coefficient
(See distribution ratio)

path length
(See range)

Pauli exclusion principle
The statement that any wave function involving several identical particles must be antisymmetric (must change sign) when the coordinates, including the spin coordinates, of any identical pair are interchanged. The principle applies to *fermions*, but not to *bosons*. If the particles in a system can be considered as occupying definite quantum states, it follows from the principle that no more than one particle of a given kind can occupy a particular state; hence the name, exclusion principle. Since electrons, protons, and neutrons are fermions, the Pauli exclusion principle must be used in the assignment of particles to quantum states in theories of atomic and nuclear structure. (*See nucleus, shell structure of*)

Pcu
The symbol for pound centigrade unit. *(See Chu)*

peaker strip (instrumentation)
A saturable core and coil located in a magnetic field for the purpose of providing a short voltage pulse at or near the time of flux reversal in the core.

pegmatite
A coarse-grained acidic rock resulting from the solidification of the last portion of a molten rock mass, usually in dykes or sills. It is of interest because certain pegmatites contain beryl and pitchblende and therefore are possible sources of beryllium and uranium.

penetrating shower
A *cosmic ray shower* in which some or all of the constituent particles are capable of greater penetration of absorbing material than is possible for electromagnetic radiation; therefore, it is not a *cascade shower*. In practice, the term usually refers to a shower that contains particles capable of penetrating more than 15 or 20 cm of lead. The particles are often pi mesons. (*See meson*)

penetration probability
The probability of transmission of a

particle through a potential barrier, a region of finite extent in which the potential energy of the particle is greater than its total energy. Classically, this probability is zero. Examples of barrier penetration are the passage of alpha particles through the barrier at the nuclear wall and the motions of electrons in a metal through the interatomic Coulomb barriers. *(Syn. transmission coefficient. See potential, nuclear)*

penetrometer (radiology)
A device for measuring the penetrating power of a beam of x-rays or other penetrating radiation by comparing transmission through various absorbers.

percentage depth dose
(See dose, percentage depth)

period
The time required for one cycle of a regularly repeated series of events. In a nuclear reactor in which the neutron flux is rising or falling exponentially, the time required for it to change by a factor of e (2.718).
(Reactor theory)

1. The asymptotic value (for large time) of the reciprocal logarithmic derivative of the reactor power.
2. The reciprocal of the time derivative of the natural logarithm of the reactor power.

(Chemistry)

1. The half-life, $t_{1/2}$.
2. In older usage, the mean life

$$\tau = t_{1/2}/(\log_e 2) = t_{1/2}/0.6931$$

period meter
A device from which an operator may read the reactor period in seconds. It may operate interlocks and scram the reactor if the period is dangerous, i.e., a few seconds or less. The device actually measures d(log neutron flux)/dt, which is the reciprocal of the period.

period range
(See intrument range)

periosteum (biology)
The tough fibrous membrane surrounding bone.

peritectic (metallurgy)
A type of phase change in which in two-component systems a liquid melt and a solid phase interact upon cooling to produce a second solid phase of composition intermediate between the two. When the liquid is present in excess, the first solid phase is completely consumed, while a deficiency of liquid produces a structure in which the remainder of the first solid phase is surrounded by the newly formed second solid phase.

permissible dose
(See dose, permissible)

personnel monitoring
(See monitoring)

perturbation theory (reactor theory)
The study of the effect of small changes on the behavior of a system.

phantom (radiology)
A volume of material behaving in essentially the same manner as tissue, with respect to the radiation in question, used to simulate a portion of the human body, and into which ionization chambers can be placed. Measurements made in a phantom permit the determination of the radiation dose delivered to the skin and points within the body. Materials commonly used for x-rays are water, Masonite (unit density), beeswax.

phase
A portion of a system which is homogeneous to the instruments of detection, or whose parts are all in the same thermodynamic state. All portions of the system which differ only in form or amount are part of the same phase.

phase diagram, constitution diagram, equilibrium diagram
A representation, either graphical or by means of a model, of the equilibrium temperature, pressure and composition limits of the phase regions of a system. In metallic systems the pressure is usually considered constant, and a binary system may be represented in two dimensions with temperature usually the ordinate and composition the abscissa. The description of ternary systems requires the use of three-dimensional models or many two-dimensional graphs.

phase shift (for scattering)
One of several angles having a value between $-\pi$ and $+\pi$, and giving the phase relationship between a scattered wave and the incident wave associated with the particle or photon which undergoes scattering; it is important in the analysis of scattering problems.

phenacite
A mineral, silicate of beryllium, Be_2SiO_4.

phosphorescence
Emission of electromagnetic radiation by a substance as a result of previous absorption of radiation generally of shorter wavelength. The emission may continue for a considerable time after cessation of the exciting irradiation, in contrast to *fluorescence*.

photodisintegration, nuclear
A nuclear reaction in which the bombarding particle is a *photon*. *(See reaction, nuclear)*

photoelectric absorption
The absorption of photons in the *photoelectric effect*.

photoelectric effect
The ejection of bound electrons from a system by photons incident on it in such a manner that the whole energy $h\nu$ of a photon is absorbed for each electron ejected. The kinetic energy E_k of the ejected electron is given by the Einstein **photoelectric equation,** $E_k = h\nu - \omega$, where ν is the frequency associated with the absorbed photon, and ω is the energy needed to remove the electron from the system. For the **surface photoelectric effect** of a solid or liquid, ω is equal to $w - w_i$, where w is the work function for the surface of the metal, and w_i is the energy of the electron in the metal. For the **atomic photoelectric effect,** also called **photoionization,** as when an electron is ejected photoelectrically from one of the inner (K, L, . . .) orbits of an atom of a gas, ω is equal to the energy of the electron in that orbit as determined by x-ray absorption measurements. *(See absorption discontinuity; quantum yield)*

photoelectric threshold
The quantum of energy $h\nu_0$ that is just sufficient to release an electron from a given system in the *photoelectric effect*. The corresponding frequency ν_0 and wavelength λ_0 are the threshold frequency and threshold wavelength, respectively. For example, in the surface photoelectric effect, the threshold $h\nu_0$ for a particular surface is the energy of a photon which, when incident on the surface, causes the electron to emerge with zero kinetic energy.

photoelectron
An electron emitted in the *photoelectric effect*.

photofluorography
(See fluorography)

photomeson
A *meson*, usually a pi meson, ejected from a nucleus by an impinging photon.

photomultiplier counter
(See scintillation counter)

photomultiplier tube
An electron multiplier tube in which the electrons initiating the cascade originate by photoelectric emission.

photon
A *quantum* of electromagnetic radiation. A photon of frequency ν has energy $h\nu$. The word photon usually refers to a plane-wave quantum, in which case the momentum is $h\nu/c$ and the component of angular momentum in the direction of the momentum is $+\hbar$.

photoneutron
A neutron released from a nucleus in a *photonuclear reaction*, for example, in a (γ, n) reaction.

photonuclear reaction
A nuclear reaction induced by a photon. In some cases the reaction apparently proceeds via a compound *nucleus* formed by absorption of the photon and distribution of its energy among the nuclear constituents; the nucleus may then "evaporate" one or more particles (*see spallation; liquid-drop model of nucleus*) or undergo photofission. (*See fission, nuclear*) In other cases the photon seemingly interacts directly with a single nucleon, which is ejected as a *photoneutron* or *photoproton* without appreciable excitation of the rest of the nucleus.

photoproton
A proton released from a nucleus in a *photonuclear reaction.*

physical mass unit
A synonym for *atomic mass unit.*

physical tracer
(See tracer)

pi meson
(See meson)

pickle (metallurgy)
The removal of metallic compounds, usually oxides, from the surface of a metal by chemical or electrochemical means. An ideal pickling solution dissolves the compound but does not attack the metal. Pickling solutions usually contain inhibitors to enhance the preferential nature of the attack.

pickup
A type of nuclear reaction in which the incident particle takes a nucleon from the target nucleus and proceeds with this nucleon bound to itself. Examples are (p,d) and (n,d) and (d,t) reactions. Pickup is the inverse of *stripping*.

pile
A nuclear reactor. The term pile comes from the first nuclear reactor, which was made by piling up graphite blocks and pieces of uranium and uranium oxide. The term reactor is becoming more commonly used. *(See nuclear reactor)*

pile oscillator
An arrangement for maintaining a neutron-absorbing body in periodic motion in a nuclear reactor. The resulting fluctuations of neutron flux can be used to measure the properties of the absorbing body of the reactor. In the latter case, the varying neutron flux gives a modulated detector output and more accurate measurement at low levels of flux.

pion
A synonym for pi meson. (*See meson*)

pipe (metallurgy)
A cavity, usually along the center line of an ingot, created by the contraction which accompanies solidification. Constituents which freeze at low temperatures may concentrate in the vicinity of the pipe.

pitchblende
A mineral consisting largely of uranium oxides; important as an ore of uranium and radium.

plait point (chemical engineering)
The point on the solubility curve of a ternary solubility diagram at which the compositions of the conjugate layers are identical.

Planck constant, h
A universal constant h that has the value 6.624×10^{-27} erg sec. It is the proportionality factor that relates the energy E of a photon to its frequency ν, that is, $E = h\nu$.

plasmagene (biology)
Postulated units of inheritance located in the cytoplasm of the cell, as distinguished from the nuclear genes located in the chromosomes.

plate column (chemical engineering)
A column containing a number of horizontal plates such as sieve plates or bubble plates, generally equally spaced one above the other.

plate efficiency (plate column)

1. **Murphree,** the ratio of actual enrichment per plate divided by the enrichment that would be obtained if complete vapor-liquid equilibrium were reached between the leaving streams.
2. **Over-all,** the ratio of the number of theoretical plates needed to the number of plates actually required. *(See stages, minimum number of theoretical)*

plateau (instrumentation)
The portion of the *plateau characteristic* for which the counting rate is approximately independent of voltage. The **length of plateau** is the voltage interval corresponding to the portion of the plateau characteristic in which a Geiger-Muller counter tube can be reliably operated.

plateau characteristic, voltage characteristic counting rate
The relation between counting rate and voltage applied to a counter tube for a given constant source of radiation. A typical curve for a Geiger-Muller counter is shown in fig. 4.

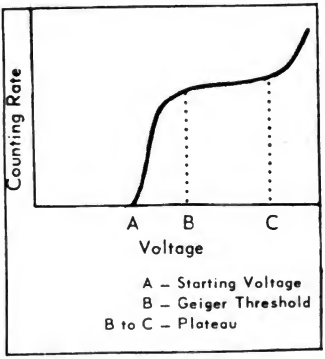

Fig. 4 Typical curve for Geiger-Muller counter

platelet, thrombocyte (biology)
A small colorless corpuscle present in large numbers in the blood of all mammals, believed to play a role in the clotting of blood.

pleochroic halo
A small spherical or (as usually observed in section) circular colored or darkened region surrounding a tiny

fragment of an alpha-emitting radioactive substance imbedded in mica and other transparent minerals. The coloration is due to crystal damage caused by the alpha particles, and the radius of the halo is equal to their range in the material, which is 10 to 50μ in most minerals. The ring-like appearance results because an alpha particle produces a maximum of ionization (and therefore of darkening) near the end of its range. Often a multiple concentric halo is observed, corresponding to emission of alpha particles of differing ranges in successive transformations in a radioactive series.

plug (reactor engineering)
A piece of material used to fill and close to radiation an aperture such as a hole in a shield.

plural scattering
(See scattering)

plutonium (Pu)
An element, artificially produced, atomic number 94, discovered in 1940 by G. T. Seaborg, E. M. McMillan, A. C. Wahl, and J. W. Kennedy. They first prepared 92y Pu^{238} by the reaction

$$U^{238}(d,\ 2n)Np^{238} \xrightarrow[(2.10d)]{\beta^-} Pu^{238}$$

The $2.41 \times 10^4 y$ Pu^{239} which is fissionable with slow neutrons is the one prepared in the nuclear reactors by the following series of reactions:

$U^{238}(n,\ \gamma)$

$$U^{239} \xrightarrow[(23.5m)]{\beta^-} Np^{239} \xrightarrow[(2.33d)]{\beta^-} Pu^{239}.$$

Other known isotopes are Pu^{232}, Pu^{234}, Pu^{236}, Pu^{237}, Pu^{240}, and Pu^{241}. Plutonium has the oxidation states +3, +4, +5, and +6, as do uranium and neptunium, but the stability of the lower oxidation states is more pronounced than in either uranium or neptunium. Because of the importance of plutonium in nuclear energy, the chemistry of plutonium is probably as well understood, in spite of its recent discovery, as that of most other elements.

plutonium reactor
A nuclear reactor in which plutonium is the principal fissionable material.

pocket chamber
A small pocket-sized ionization chamber used for monitoring radiation exposure of personnel. Before use it is given a charge and the amount of discharge is a measure of the quantity of radiation received.

pocket meter
A complete pocket-sized radiation instrument by means of which a quantity of radiation can be directly indicated.

point counter tube
A counter tube, using gas amplification, in which the central electrode is a point (Geiger counter) or a small sphere (Geiger-Klemperer counter).

poison
Material of high-absorption cross section that absorbs neutrons unproductively and reduces the reactivity of a reactor. It may be an accumulation of material resulting from operation, especially fission products of high neutron-absorption cross section. Sometimes applied only to unwanted elements.

polonium (Po)
An element, atomic number 84, discovered in 1895 by Pierre and Marie Curie. No stable isotopes are known. The longest-lived naturally occurring isotope is the 138.3d Po^{210} (RaF); the longest-lived synthetic isotope is 3.0y Po^{208}. Other isotopes are

known. The chemistry of polonium is similar to that of tellurium. Oxidation states +2, +4, and +6 are known.

polycythemia (biology)
A condition in which the count of red corpuscles in the blood is abnormally high. It is found as a normal response to high altitudes, for instance, or may be a manifestation of disease, as in polycythemia vera.

polymorphonuclear leucocyte, granulocyte (biology)
A leucocyte characterized by an irregular deep-staining nucleus. Frequently these appear to be several separate nuclei; however, close inspection will disclose delicate connecting bands. The cytoplasm is abundant and contains numerous fine granules. These granules establish a subclassification for these cells as to their affinity for basic or acid stain, or their lack of affinity for either stain. They constitute 65% to 75% of all leucocytes, and are prominent in acute inflammatory processes, and may be reduced in number following irradiation.

poor geometry
(See geometry, poor)

porous reactor
A nuclear reactor composed of a porous material or aggregate of small particles with coolant or fluid fuel flowing through the pores.

positive rays
A stream of positively charged atoms or molecules, produced by a suitable combination of ionizing agents, accelerating fields, and limiting apertures.

positron
A positive *electron*. Positrons are formed in the process of *pair production*, in the *beta decay* of many radionuclides, and in some more specialized processes.

positronium
A quasi-stable system consisting of a positron and an electron bound together. Its set of energy levels is similar to that of the hydrogen atom. However, because of the different reduced mass, the frequencies associated with its spectral lines are approximately half of those of the corresponding hydrogen lines. The mean life of positronium is at most about 10^{-7} sec, its existence being terminated by electron-positron *annihilation*.

potassium (K)
A metallic element, nineteenth in the atomic series, with melting point 62.3°C and moderate thermal neutron-absorption cross section. It has been suggested for use as a liquid-metal heat-transfer fluid.

potential, nuclear
The potential energy V of a nuclear particle as a function of its position in the field of a nucleus or of another nuclear particle. A **central potential** is one that is spherically symmetric; that is, V is a function only of the distance r from the center of the field, thus being the same in all directions, and is representable by a curve as in figs. 5, (A) – (F). A **potential well** is the region about a minimum in the potential; it results from attractive forces. A **potential barrier** is the region about a maximum in the potential; it results from repulsive forces, either alone or in combination with attractive forces. Some central potentials commonly used as approximations to nuclear potentials are illustrated in fig. 5. (A) shows a **square well potential,** which has a constant negative value $-V_0$ for $r \leqslant r_0$, and zero value for $r \geqslant r_0$. When this curve represents

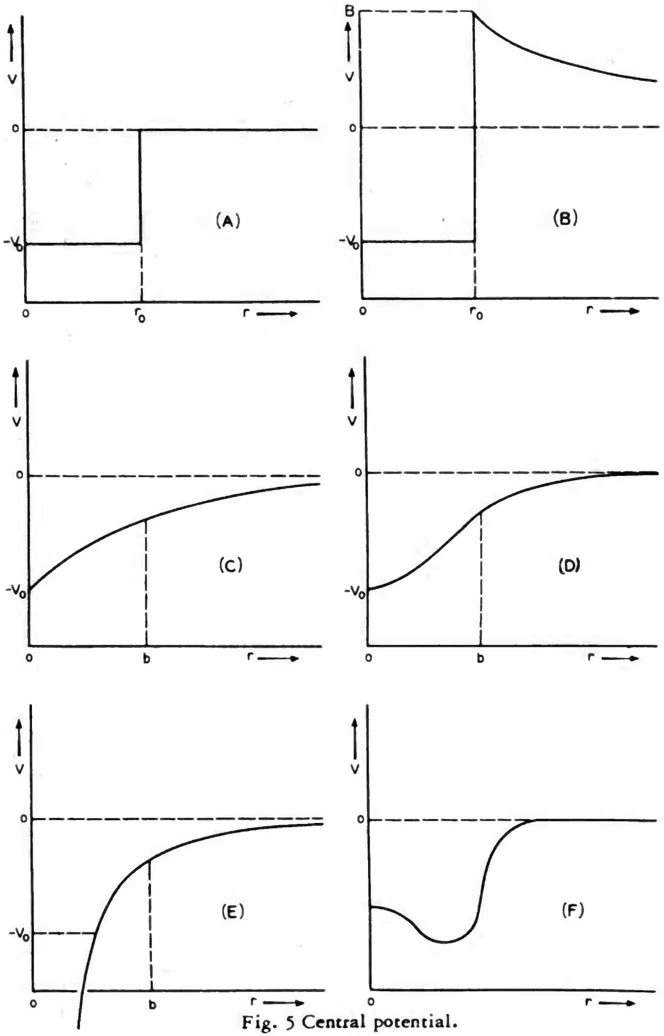

Fig. 5 Central potential.

the potential between two nucleons, r_0 is called the **range of nuclear forces**; when it represents the potential of a nucleus, for a nucleon, r_0 is called the nuclear radius (*see radius, nuclear*). (*B*) shows a square well potential for $r \nless r_0$, with a *Coulomb potential* resulting from repulsive electrostatic forces, for $r > r_0$. The resulting barrier is called a **Coulomb barrier**, and the maximum energy *B* is called the **barrier height.** Such a potential approximates that of a positively charged particle in the field of a nucleus, and is often used in the theory of alpha disintegration and nuclear reactions. (*C*) shows an **exponential well,** $V = -V_0 e^{-r/b}$. (*D*) shows a **Gaussian well,** $V = -V_0 e^{-r/b^2}$. (*E*) shows the **Yukawa potential,** $V = -(V_0 b/r) e^{-r/b}$, used in the meson theory of nuclear forces for the interaction between two nucleons. (*F*) shows a **wine-bottle potential**, characterized by a low central elevation. If a high central elevation is present, the resulting barrier is called a **central barrier.**

potential energy, nuclear
The average total potential energy of all of the nucleons in a nucleus due to the specifically *nuclear forces* between them, but excluding the electrostatic potential energy.

potential scattering
(See scattering)

potential well
(See potential, nuclear)

powder pattern (radiography)
An x-ray diffraction pattern obtained from a sample consisting of many small crystals oriented at random. This may be obtained by using a photographic film bent in the form of a cylinder with its axis perpendicular to the x-ray beam at the specimen. The developed film consists of a central spot surrounded by a series of concentric rings from whose diameters the Bragg angles may be computed.

power breeder
A nuclear reactor designed to produce both useful power and fuel.

power coefficient (reactor engineering)
The change of reactivity with increase in power. In a heterogeneous reactor it differs from the temperature coefficient because of the temperature differences of fuel, moderator, and coolant.

power control rod
A rod for controlling the power level of a nuclear reactor. *(See control rod)*

power density
Power generation per unit volume of reactor core.

power range
Range of power level in which a nuclear reactor is designed to operate. *(See counter range; instrument range)*

power reactor
(See nuclear reactor)

precipitation hardening
(See age hardening)

preferred orientation
(See orientation)

preformed precipitate (chemistry)
A precipitate used for coseparation of tracer, which has been formed before admixture with the tracer species to be adsorbed. This may be prepared by addition of one constituent of the precipitate to a solu-

tion of the tracer with a large excess of the precipitating reagent. The preformed precipitate forms at the point of contact of reagents and is exposed later, on mixing, to the tracer to be adsorbed. The term is also applied to adsorbing precipitates formed outside of the system and then added.

primary circuit
(See thermal cycle)

primary cosmic rays
(See cosmic rays)

primary fission yield
(See fission yield, independent)

primary ionization
1. In collision theory, the ionization produced by the primary particles as contrasted to the total ionization (*see ionization, total*) which includes the secondary ionization produced by delta rays.
2. In counter tubes, the total ionization produced by incident radiation without gas amplification.

production reactor
A nuclear reactor designed primarily for large-scale production of transmutation products (e.g., plutonium).

promethium (Pm)
An element, atomic number 61 having no known stable isotopes in nature. The first separation with detailed identification of synthetic isotopes was carried out in 1945 by J. A. Marinsky and L. E. Glendenin, with fission products and $\beta-$ decay products of neutron irradiated neodymium. The element is named after the mythological titan, Prometheus. The 4y Pm^{147} is available in quantity from nuclear fission. The longest-lived isotope known is 30y Pm^{145}. The element is a member of the rare earth series, with oxidation state +3 as the only one known.

prompt-critical
Capable of sustaining a chain reaction without the aid of delayed neutrons. (Reactor engineering) The condition of a nuclear reactor that is critical (effective multiplication constant = 1) because of prompt neutrons alone without requiring the contribution of delayed neutrons. If a reactor is supercritical on prompt neutrons the reaction rate will rise rapidly because the time required for the average neutron cycle is extremely short. A reactor in this condition is very difficult to control. (*See delayed-critical*)

prompt fission neutrons
(See fission neutrons)

prompt gamma
Gamma radiation emitted at the time of fission of a nucleus.

prompt neutrons
Those neutrons released coincident with the fission process, as opposed to the neutrons subsequently released.

prophase (biology)
The first stages of mitosis, during which the chromosomes shorten and thicken preparatory to forming a metaphase plate.

proportional counter
An instrument comprising a proportional counter tube with its associated circuits. Often loosely applied to the proportional counter tube itself.

proportional counter tube
A radiation counter tube or chamber operated in the proportional region.

proportional ionization chamber
An ionization chamber in which the initial ionization current is amplified by electron multiplication in a region of high electric field strength, as it

is in a proportional counter; used for measuring ionization currents or charges over a period of time, not for counting.

proportional region
The range of operating voltage for a counter tube or ionization chamber in which the gas amplification is greater than one and is independent of the primary ionization. In this region the pulse size is proportional to the number of ions produced as a result of the initial ionizing event.

protactinides
A name proposed for elements of the last row of the periodic system in oxidation state +5, in which state compounds are presumed to be isostructural with the corresponding ones of protactinium. (*See actinides*; *protactinium*)

protactinium (Pa)
An element, atomic number 91, discovered by O. Hahn and L. Meitner in 1917. They identified 3.43×10^4y Pa^{231} as the parent of Ac^{227}. Other radioactive isotopes of protactinium are known, among which is Pa^{233}, an intermediate in the preparation of the fissionable U^{233} from thorium. The most stable oxidation state is +5; a +4 state is also known. In the older literature the spelling "protoactinium" is often found.

protection (radiology)
Provisions designed to reduce exposure of personnel to radiation. For external radiation, this consists in the use of protective barriers of radiation-absorbing material, in ensuring adequate distance from radiation sources, in reducing exposure time, or in combinations of these. For internal sources, it involves measures to restrict inhalation, ingestion, or other modes of entry of radioactive materials into the body.

protection survey
Evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

protium
A name sometimes applied to the hydrogen isotope of mass 1 ($_1H^1$), in contradistinction to *deuterium* ($_1H^2$) and *tritium* ($_1H^3$).

proton

1. A positively charged *elementary particle* of mass number 1 and charge equal in magnitude to the electronic charge e. It is one of the constituents of every nucleus; the number of protons in the nucleus of each atom of an element is given by the atomic number Z of the element. Other properties of the proton are: rest mass, 1.67×10^{-24} gm, or 1.0075 amu; magnetic moment, 2.79245 nuclear magnetons, or 1.52×10^{-3} dyne cm $gauss^{-1}$; spin quantum number, ½; described by Fermi-Dirac statistics.
2. The nucleus of an atom of hydrogen of mass number 1.

proton-proton chain
A series of thermonuclear reactions initiated by a reaction between two protons, namely, $H^1 + H^1 \longrightarrow H^2 + \beta^+ + \nu$, that provides the energy of some stars. The subsequent reactions are presumed to be $H^2 + H^1 \longrightarrow He^3 + \nu$, followed by $He^3 + He^3 \longrightarrow$

$He^4 + H^1 + H^1$. The net result is the same as in the *carbon cycle*, namely, the synthesis of four hydrogen atoms into one helium atom, with the liberation of the mass difference as energy. It is thought that the proton-proton cycle is more important than the carbon cycle in the cooler stars, and that the reverse is true in the hotter stars. Both cycles are believed to be important in the sun. (*See reaction, thermonuclear*)

proton-synchrotron
(See synchrotron)

pulse amplifier
An amplifier, designed specifically to amplify the intermittent signals of a nuclear detector, incorporating appropriate pulse-shaping characteristics.

pulse height analyzer
An electronic circuit which sorts and records the pulses according to height.

pulse height discriminator
A circuit designed to select and pass voltage pulses of a certain minimum amplitude.

pulse height selector
A circuit designed to select and pass voltage pulses in a certain range of amplitudes.

pulse ionization chamber
An ionization chamber employed to detect individual ionizing events.

purpura (biology)
Hemorrhagic spots in or under the skin or mucous membranes.

Q

Q-value
The energy, Q, released or absorbed in a nuclear reaction. A synonym for *disintegration energy, nuclear.*

quality (radiobiology)
A term for the approximate characterization of radiation with regard to its penetrating power. It is usually expressed in terms of *effective wavelengths* or *half-value layer.*

quantum
An observable quantity is said to be **quantized** when its magnitude is, in some or all of its range, restricted to a discrete set of values. If the magnitude of the quantity is always a multiple of a definite unit, then that unit is called the **quantum** (of the quantity). For example, the quantum or unit of orbital angular momentum is h, and the quantum of energy of electromagnetic radiation of frequency ν is $h\nu$. In field theories, a field (or the field equations) is quantized by application of a proper quantum-mechanical procedure and this results in the existence of a **fundamental field particle,** which may be called the **field quantum.** Thus the photon is a quantum of the electromagnetic field and in nuclear field theories the meson is considered to be the quantum of the nuclear field.

quantum number
A number assigned to one of the various values of a quantized quantity in its discrete range. The quantum numbers arise from the mathematics of the eigenvalue problem and may be related to the number of nodes in the eigenfunction. When the quantity has a *quantum,* the quantum number is the number of such quantums. A state may be described by giving a sufficient set of compatible quantum numbers. In the customary formulations, each quantum number is either an integer (which may be positive, negative or zero) or an odd half-integer. For a nucleus the quantum numbers of most interest are the total angular momentum quantum number (called the nuclear spin quantum number) and the *parity. (See angular momentum)*

quantum statistics
Statistics of the distribution of particles of a given type among the various possible energy values, taking quantization of the latter into account. In the **Fermi-Dirac statistics,** no more than one of a set of identical particles may occupy a particular quantum state, whereas in the **Bose-Einstein statistics,** the occupation number is not limited in any way. Particles described by these statistics are sometimes called **fermions** and **bosons,** respectively. No particle has been found to be neither a fermion nor a boson. All known fermions have total angular moments $(n + \frac{1}{2})$ h, where n is zero, or an integer, and all known bosons have angular momentums n h. At sufficiently high temperatures, where a large number of energy levels are excited, both quantum statistics re-

duce to the classical **Maxwell-Boltzmann statistics**. The basis of the two quantum statistics is the observation that any wave function that involves identical fermions is always antisymmetric with respect to interchange of the coordinates, including spin, of any two of the fermions, whereas for identical bosons, the wave function is always symmetric.

quantum yield
The number of photon-induced reactions of a specified type per photon absorbed. In the *photoelectric effect*, the quantum yield is more commonly called the photoelectric efficiency. In photochemistry it is the ratio of the number of reactions induced both directly and indirectly by light to the number of photons absorbed; a quantum yield greater than unity indicates a chain reaction. In plant physiology it is the ratio of the number of reactions of the primary photochemical step of photosynthesis (as yet undetermined) to the number of photons absorbed.

quenching
The process of inhibiting continuous or multiple discharges in a counter tube which uses gas amplification.

quenching circuit
A circuit which diminishes, suppresses or reverses the voltage applied to a counter tube in order to inhibit multiple discharges from a single ionizing event.

R

r
Abbreviation for *roentgen.*

R
The symbol for the *Rydberg constant.*

rabbit (reactor engineering)
A small container propelled, usually pneumatically or hydraulically, through a tube in a nuclear reactor for exposing substances experimentally to the radiation and neutron flux of the active section; used for rapid removal of samples containing atoms with very short half-lives. Sometimes called **shuttle.** As used in isotope separation, see *single-stage recycle.*

race track, or **track** (isotopes separation)
An assembly of several calutrons in the shape of a race track, having a common magnetic field. *(See calutron)*

rad
One hundred ergs of absorbed energy per gram of absorbing material.

radiation
1. The emission and propagation of energy through space or through a material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves.
2. The energy propagated through space or through a material medium as waves; for example, energy in the form of electromagnetic waves or of elastic waves. The term radiation, or radiant energy, when unqualified, usually refers to electromagnetic radiation; such radiation commonly is classified, according to frequency, as Hertzian, infrared, visible (light), ultraviolet, x-ray, and gamma ray.
3. In heat transfer, the reference is usually to the infrared spectrum. (*See photon*)
4. By extension, corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type, as cosmic radiation.

radiation, characteristic
Radiation originating from an atom following removal of an electron. The wavelength of the emitted radiation depends only on the element concerned and the particular energy levels involved.

radiation, heterogeneous
Radiation having several different frequencies, or a beam of particles of a variety of energies or containing different types of particles.

radiation, homogeneous
Radiation having an extremely narrow band of frequencies, or a beam of monoenergetic particles of a single type.

radiation, monochromatic
Electromagnetic radiation of a single wavelength, or in which all the photons have the same energy.

radiation, monoenergetic
Particulate radiation of a given type (alpha, beta, neutron, etc.) in which all particles have the same energy.

radiation, multipole
The radiation field in free space may be expanded into multipole fields, electric and magnetic, as well as into plane waves. Each multipole radiation field is characterized by the numbers l, m, and by its *parity*. An electric multipole radiation, l, m, has a pure transverse magnetic field and a parity $(-1)^l$. A magnetic multipole radiation, l, m, has a pure transverse electric field and a parity $-(-1)^l$. A single photon of multipole radiation l, m, whether electric or magnetic, has an energy $\hbar\nu$ and an angular momentum $l\hbar$ with component $m\hbar$ in the Z-direction. Multipoles with $l = 0$ do not exist; those with $l = 1$ are termed **dipole,** with $l = 2$, **quadrupole,** and so forth. The amplitudes of the various multipole radiations emitted by a moving charge and magnet distribution are proportional to the *multipole moments* of the distribution. In a nuclear transition, these moments depend on the initial and final states.

radiation, secondary
Particles or photons produced by the interaction with matter of a radiation regarded as primary. Examples are secondary *cosmic rays, photoelectrons, Compton recoil electrons, delta rays,* the electrons liberated from a dynode of a photomultiplier tube when struck by an electron accelerated from the preceding dynode, recoil protons from neutron-proton collisions, and *bremsstrahlung* radiation.

radiation chemistry
That branch of chemistry which is concerned with the chemical effects (including discomposition) of high energy radiation and particles on matter.

radiation counter tube
A radiation detector capable of providing discrete electrical pulses in response to the incidence of radiation.

radiation damage
A general term for the effects of radiation (gamma rays, fission fragments, and neutrons) upon substances. Dissociation of compounds may occur. Gases may be evolved. Changes in solids are related also to disruption of crystal structure and include changes in mechanical properties and dimensions, thermal conductivity, electrical conductivity, etc.

radiation length
The mean path length required for the reduction, by the factor $1/e$, of the energy of relativistic charged particles as they pass through matter. Such particles lose their energy mainly by radiating *(see bremsstrahlung).* The radiation length for relativistic electrons in air is 330 cm; in lead it is 0.5 cm.

radiation sickness (radiobiology)
(Radiation therapy) A self-limited syndrome characterized by nausea, vomiting, diarrhea, and psychic depression, following exposure to appreciable doses of ionizing radiation, particularly to the abdominal region. Its mechanism is unknown and there is no satisfactory remedy. It usually comes on a few hours after a treatment and may subside within a day. It may be sufficiently severe to necessitate interrupting the treatment series, or to incapacitate the patient.

(Atomic bomb disaster) A syndrome following intense acute exposure to ionizing radiations. A few hours after exposure nausea and vomiting appear, last a few hours and then subside for a variable interval. After this quiescent period, a recurrence of nausea and vomiting is accompanied by mucous or bloody diarrhea, purpura, epilation, and agranulocytic infections. The illness may vary in severity, and may go on to death, or partial or apparently complete recovery may ensue. The more intense the early symptoms and the shorter the period of remission, the more serious the final outcome.

radiation therapy (radiobiology)
Treatment of disease with any type of radiation. Treatment of disease with any ionizing radiation is termed **radiotherapy.**

radiative capture
(See capture, radiative)

radio-
A prefix denoting radioactivity or relationship to it.

radioactinium (RdAc)
The common name for 18.6*d* Th^{227}, a member of the *actinium series.*

radioactive
1. Exhibiting radioactivity.
2. Pertaining to radioactivity.

radioactive chain
A synonym for *radioactive series.*

radioactive contamination
(*See contamination, radioactive*)

radioactive decay
(*See radioactivity; decay, radioactive*)

radioactive decay constant
(See decay constant)

radioactive decay law
(See decay law, radioactive)

radioactive decay series
(See decay chain)

radioactive displacement law
A law stated by Soddy and Fajans originated from the circumstance that a change in atomic number results in a displacement of the daughter relative to the parent in the periodic table of the elements. In its more modern and inclusive form it may be stated as follows: When a nucleus emits an alpha particle the new nucleus formed has an atomic number two less than the parent and a mass number of four less. When a nucleus emits a negative beta particle the atomic number of the new nucleus formed is one greater than the parent and the mass number remains the same. The emission of a positron or the capture of an orbital electron decreases the atomic number by one without changing the mass number. *Isomeric transition* and gamma emission lead to no change in atomic number or mass number. The changes in atomic number ΔZ and mass number ΔA of a nuclide that accompany the various types of radioactive disintegration are indicated in Table II

Table II

Type of disintegration		ΔZ	ΔA
Alpha		−2	4
Beta	electron emission	+1	0
	positron emission	−1	0
	electron capture	−1	0
Isomeric transition		0	0

radioactive equilibrium
A condition which may obtain in the course of the decay of a radioactive parent having shorter-lived descendants, in which the ratio of the activity of the parent to that of a descendant is independent of time. This condition can exist only when no activity longer-lived than that of the parent is interposed in the decay chain. If the parent element has a very much longer lifetime than the succeeding ones, so that there is no

appreciable change in its amount in the time interval required for the later products to attain equilibrium, then, after that condition is reached, equal numbers of atoms of all members of the series disintegrate in unit time. This condition, known as **secular equilibrium,** is never actually attained, but is essentially established in such a case as radium and its series through radium C. The half-life of radium is 1590 years, of radon, 3.82 days, and of each of the subsequent members, a few minutes. After about a month essentially the equilibrium amount of radon is present, and then for a long time all members of the series disintegrate the same number of atoms per unit time. When secular equilibrium exists among members A, B, C,... etc., of a decay series, then $N_A\lambda_A = N_B\lambda_B = N_C\lambda_C = \ldots$. where N_A, N_B, N_C,... are the numbers of atoms of A, B, C,..., respectively, and λ_A, λ_B, λ_C,... are the corresponding decay constants. If the lifetime of the parent is sufficiently short, so that the quantity present decreases appreciably during the period under consideration, but is still longer than that of successive members of the series, a stage of **transient equilibrium** will be reached, after which all members of the series decrease in amount exponentially with the period of the parent. An example of this is radon, with a half-life of 3.82 days, and the successive members of the series through radium C. When transient equilibrium exists between a parent, A, and daughter, B, then $N_A\lambda_A = N_B(\lambda_B - \lambda_A)$, where N_A and N_B are the number of atoms and λ_A and λ_B the respective decay constants.

radioactive half-life
The time in which the amount of a particular radioactive isotope is reduced to half of its initial value. *(See half-life)*

radioactive heat
A synonym for radiogenic heat. *(See radiogenic)*

radioactive nuclides, natural
(See radioactivity, natural)

radioactive period
(See period)

radioactive series
A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the *parent,* the intermediate members are called *daughters,* and the final stable member is called the *end product.* Three such series are encountered in natural radioactivity, and many others are encountered in *induced radioactivity,* particularly among the heavy elements and fission products. (*See radioactivity, natural*) The process of successive radioactive transformations in such a series is known as **series disintegration.** A series of induced radionuclides that merges into a natural series is called a **collateral series** to the latter. *(See decay chain. See also actinium, neptunium, thorium, and uranium series)*

radioactive standard
A sample of radioactive material, usually with a long half-life, in which the number and type of radioactive atoms at a definite reference time is known. Hence, it may be used as a radiation source for calibrating radiation measurement equipment.

radioactive tracer
Small quantity of radioactive isotope, either with carrier or carrier-free, used to follow biological, chemical, or other processes. Since

the stable and radioactive isotopes of an element have essentially the same chemical properties, and the radioactive ones are readily detected, the movement and behavior of the stable atoms can be traced by following the radioactivity. In this case the compound under observation is said to be labeled with the radioactive isotope. *(See tracer)*

radioactive transformation
(See decay, radioactive)

radioactivity

1. Spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiations. The principal types of radioactivity are *alpha disintegration, beta decay* (negatron emission, positron emission, and electron capture), and *isomeric transition. Double-beta decay* is another type that has been postulated, and spontaneous *fission* and the spontaneous transformations of mesons are sometimes considered as types of radioactivity. To be considered as radioactive, a process must have a measurable lifetime between $\sim 10^{-10}$ sec and $\sim 10^{17}$ yr, according to present experimental techniques. Radiations emitted within a time too short for measurement are called prompt; however, prompt radiations, including gamma rays, characteristic x-rays, conversion and Auger electrons, delayed neutrons, and annihilation radiation, are often associated with radioactive disintegrations, since their emission may follow the primary radioactive process.
2. A particular radiation component from a radioactive source, such as gamma radioactivity.
3. A radionuclide, such as a radioactivity produced in a bombardment.
4. A synonym for *activity* (df. 1.) *(See decay, radioactive)*

radioactivity, natural
Radioactivity exhibited by naturally occurring substances. **Natural radionuclides** may be classified as follows: (i) **primary,** which have lifetimes exceeding several hundred million years, and which presumably have persisted from the time of nucleogenesis to the present; they include the alpha emitters U^{238}, U^{235}, Th^{232} and Sm^{147}, and the beta-active nuclides K^{40}, Rb^{87}, La^{135}, In^{115}, Lu^{176}, and Re^{187}, (ii) **secondary,** which have geologically short lifetimes and are decay products of primary natural radionuclides; all presently known members of this class belong to the elements from thallium to uranium (those derived from U^{238} are members of the *uranium,* or *radium, series,* those from U^{235}, of the *actinium series,* and those from Th^{232}, of the thorium series), (iii) **induced,** which have geologically short lifetimes and are products of nuclear reactions occurring currently or recently in nature; examples are C^{14} (natural radiocarbon, produced by cosmic ray neutrons in the atmosphere, and Pu^{239}, produced in uranium minerals by neutron capture; (iv) **extinct,** which have lifetimes that are too short for survival from the time of nucleogenesis to the present, but long enough for persistence into early geologic times with measurable effects; at present I^{129} is the only suspected member of this class.

radioautograph
(See autoradiograph)

radiobiologic action
The effect of radiation upon living matter.

radiobiology
That branch of biology which deals

with the effects of radiation on biological systems.

radiocarbon age; radiocarbon dating
(*See age*)

radiochemical analysis
The determination of the absolute disintegration rate of a radionuclide in a mixture based on the counting rate of a sample that has been separated and purified, in measured yield, by appropriate chemical procedures.

radiochemistry
The aspects of chemistry connected with radionuclides and their properties, with the behavior of minute quantities of radioactive materials by means of their radioactivity and with the use of radionuclides in the study of chemical problems.

radio-colloid
Radioactive atoms in colloidal aggregates.

radioelement
A form or sample of an element containing one or more radioactive isotopes. The prefix "radio" before the name of an element indicates a particular radioelement, as radiocarbon, radiolead. To avoid ambiguity, the prefix "radio" should not be used to indicate *radiogenic*; thus, radiolead should not be used as a synonym for radiogenic lead. (Chemistry) An element with no stable isotopes.

radiogenic
Produced by radioactive transformation. Thus, uranium minerals contain radiogenic lead and radiogenic helium. The heat produced within the earth by the disintegration of radioactive nuclides is known as **radiogenic heat.**

radiograph
A photographic image formed as a result of differential absorption of penetrating radiation.

radiography
The making of shadow images on photographic emulsion by the action of ionizing radiation. The image is the result of the differential absorption of the radiation in its passage through the object being radiographed.

radioisotope
1. Any radioactive isotope of an element.
2. A word loosely used as a synonym for radionuclide.

radiology
The medical science of radioactive substances, x-rays, and other ionizing radiations, and the application of the principles of this science to diagnosis and treatment of disease. *(See roentgenology)*

radioluminescence
Light emissions caused by radiations from radioactive substances.

radiometric analysis
A method of quantitative chemical analysis for a radioactive component with a known specific activity based on the measurement of its absolute disintegration rate.

radionuclide
A synonym for radioactive nuclide. *(See radioactivity, natural)*

radioresistance
Relative resistance of cells, tissues, organs, or organisms to the injurious action of radiation. The term may also be applied to chemical compounds

or to any substance. (*See also radiosensitivity*)

radiosensitivity
Relative susceptibility of cells, tissues, organs, organisms, or any substances to the injurious action of radiation. *Radioresistance* and radiosensitivity are at present employed in a qualitative or comparative sense, rather than in a quantitative or absolute one.

radiotherapy
Treatment of disease with any ionizing radiation. *(See radiation therapy)*

radiothorium (RdTh)
The common name for 1.90*y* Th^{228}, a member of the *thorium series*.

radium (Ra)
An element, atomic number 88, discovered in pitchblende by Marie and Pierre Curie in 1895 and first isolated in 1902. The most prominent isotope, 1620*y*, alpha-emitting Ra^{226} is a member of the uranium decay series. The chemistry of radium is very similar to that of barium.

radium A (RaA)
The common name for 3.05*m* Po^{218} a member of the *uranium series*.

radium B (RaB)
The common name for 26.8*m* Pb^{214}, a member of the *uranium series*.

radium C (RaC)
The common name for 19.7*m* Bi^{214}, a member of the *uranium series*.

radium C′ (RaC′)
The common name for $1.47 \times 10^{-4} s$ Po^{214}, a member of the *uranium series*.

radium C″ (RaC″)
The common name for 1.32*m* Tl^{210}, a member of the *uranium series*.

radium D (RaD)
The common name for 22*y* Pb^{210}, a member of the *uranium series*.

radium E (RaE)
The common name for 4.85*d* Bi^{210}, a member of the *uranium series*.

radium E″ (RaE″)
The common name for 4.23*m* Tl^{206}, a member of the *uranium series*.

radium F (RaF)
The common name for 138.3*d* Po^{210}, a member of the *uranium series*.

radium G (RaG)
The common name for Pb^{206}, the stable end-product of the *uranium series*. Natural lead contains 23.69% of this isotope.

radium age
(See age)

radium series
(See radioactivity, natural)

radius, nuclear
The radius *R* of a spherical volume within which the density of nucleons in a nucleus is large. It is not a precisely determinable quantity. Theory indicates that the density of nucleons tapers off gradually at the edge of the nuclear volume and that this volume is somewhat aspherical. Each type of experiment serving to determine the radius of a nucleus yields a slightly different value. Thus it is sometimes necessary to specify the **neutron collision radius,** determined by fast-neutron transmission experiments; the **Coulomb,** or **Gamow, barrier radius,** deduced from the rate of alpha disintegration or from cross sections of nuclear reactions involving charged particles; the **electrostatic radius,** deduced from an analy-

sis of nuclear binding energies, especially of **mirror nuclides.** The **radius parameter** r_o is the effective radius of a nucleus divided by the cube root of its mass number A. All experiments yield approximately the same value of r_o for all nuclei, thus indicating that nuclei have about the same density. The value of r_o is approximately 1.4×10^{-13} cm. Thus the formula $R = r_o A^{1/3} = 1.4 \times 10^{-13} A^{1/3}$ cm is reasonably good for calculating the radius of any nucleus.

radius of electron, classical
(See electron radius, classical)

radon (Rn)

1. Em^{222}, an alpha-emitter with a half-life of 3.825*d*, a member of the *uranium series.*
2. A name often used for element 86; also called *emanation.* Now officially called radon.

raffinate layer
The liquid layer in a solvent extraction system from which a solute has been extracted.

random coincidence
(See coincidence)

range

1. The thickness of matter, expressed in length or in mass per unit area required to remove all detectable high speed charged particles from a beam by slowing them down below the threshold for measurement.
2. The distance that a particle will penetrate a given substance before its kinetic energy is reduced to a value below which it can no longer produce ionization. For a heavy ion, such as a proton or an alpha particle, the range usually refers to the component of displacement in the initial direction; it is only slightly shorter than the **path length,** or distance measured along the track of the particle. For a meson, whose track shows moderate deflections near the end, the range usually refers to the path length. For an electron, whose track may be quite tortuous because of frequent deflections, the range usually refers to the greatest distance of penetration in a specified direction; this distance may be considerably shorter than the path length. The **residual range** is the distance over which the particle can still produce ionization after having already lost some of its energy in passing through matter. Because of the phenomenon of *straggling,* particles of a given kind and of the same initial energy do not all have the same range. For heavy ions, the ranges are distributed, in a manner similar to the normal probability distribution, about the **mean range,** or range that is exceeded by half of the particles. The **extrapolated range** is the intercept on the range-axis of a straight line drawn through the descending portion of a numbers-versus-range curve for initially monoenergetic particles; it exceeds the mean range by a few per cent. The **maximum range** for a group of ionizing particles is the greatest distance in a specified direction at which their ionization can be detected. The **linear range** is the range expressed in units of length. The **mass range** is the range expressed in units of **surface density;** it is thus the mass per unit area of a layer of thickness equal to the linear range, and is equal to the product of the linear range and the density of the substance. *(See Bragg curve)*

range, extrapolated
The value of the range in matter, for a given type of charged particle, obtained by an extrapolation of the absorption curve according to some prescription. For heavy charged particles (protons, deuterons, helium ions) the usual prescription involves tangential extrapolation to the zero ordinate from the point of half-reduction of the beam intensity.

range, visual
The value of the range of beta particles in an absorber, usually aluminum, estimated by visual inspection of breaks in the aluminum absorption curve. (*Cf. Feather analysis*)

range-energy relation
The relation, usually expressed in the form of a graph, between the *range* of particles of a given type and initial kinetic energy, and the energy. Empirical correlations have frequently been made between observable ranges, R, of beams of particles and the initial kinetic energy, E, of the particles, or for beta particles, the initial maximum energies E_m. The correlations are best represented graphically, but approximate equations are often used. For mean helium ion (alpha particles) ranges between 3 and 7 cm, a typical relation for the extrapolated range R_α (in cm of air at 1 atm and 15° C) versus the energy E (in Mev) is

$$\bar{R}_\alpha = 0.318E^{3/2}$$

For fast electrons, or beta rays, a typical relation for the range R_e, in mg/cm^2 of aluminum, versus the maximum energy, E_{max} (in Mev) is

$$R_e = 0.542E_{max} - 0.133$$

where $E_{max} > 0.6$ Mev

For lower energies a plot of previously established data is usually used. *(See Feather analysis)*

range straggling
(See range)

rate meter
(See counting-rate meter)

rate of exchange (chemistry)
The rate of a reaction in which atoms of the same element in two different molecular species or in two different sites in the same molecular species exchange places. It is usually expressed in moles liter^{-1} sec^{-1}. Although such a reaction can ordinarily not be observed unless one of the reacting species is isotopically labeled, the rate of the exchange reaction is independent of the concentration or even of the existence of the tracer. If, at time $t = 0$, only one of the exchanging species is labeled, and if the overall concentrations (e.g., in moles/liter) of the exchanging species are a and b, then the rate of exchange, R, is related to the *half-time of exchange t* as follows:

$$R = \frac{ab}{a+b} \cdot \frac{\log_e 2}{t_{1/2}} = \frac{ab}{a+b} \cdot \frac{0.6931}{t_{1/2}}.$$

Rayleigh distillation
A simple distillation, wherein the composition of the residue changes continuously during the course of the distillation. By analogy, any process which follows the same mathematical relationship.

reaction, nuclear
An induced nuclear disintegration, that is, a process occurring when a

nucleus comes into contact with a photon, an elementary particle, or another nucleus. In many cases the reaction can be represented by the symbolic equation

$$X + a \longrightarrow Y + b$$

or, in abbreviated form,

$$X\ (a,\ b)\ Y,$$

in which X is the target nucleus, a is the incident particle or photon, b is an emitted particle or photon, and Y is the product nucleus. An example is

$${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1,$$

the abbreviated notation for which is

$$N^{14}\ (a,\ p)\ O^{17}$$

In some nuclear reactions more than one particle is emitted; an example is

$$Mn^{55}\ (d,\ a3n)\ Cr^{50}$$

(Synonym for nuclear photodisintegration.)

reaction, nuclear induced
A process in which a nucleus interacts with another nucleus, an elementary particle or photon, to produce in time of the order of 10^{-12} seconds or less one or more other nuclei (and possibly neutrons, mesons, neutrinos, photons, etc.). *(Cf. reaction, nuclear)*

reaction, nuclear spontaneous
Radioactive decay.

reaction, thermonuclear
A nuclear reaction in which the energy necessary for the reaction is provided by colliding particles that have kinetic energy by virtue of their thermal agitation. Such reactions occur at appreciable rates only for temperatures of millions of degrees and higher, the rate increasing enormously with temperature. The energy of most stars is believed to be derived from exothermic thermonuclear reactions. *(See carbon cycle; proton-proton chain)*

reaction energy, nuclear, Q

1. The *disintegration energy* of a nuclear reaction. It is equal to the sum of the kinetic or radiant energies of the reactants minus the sum of the kinetic or radiant energies of the products. (If any product of a specified reaction is in an excited nuclear state, the energy of subsequently emitted gamma radiation is not included in the sum.)
2. Often, implicitly, the **ground-state nuclear reaction energy,** which is the reaction energy when all reactant and product nuclei are in their ground states; symbol Q_o.

reaction rate
The rate at which fission takes place in a nuclear reactor, most fundamentally expressed as a number of nuclei undergoing fission per unit time. Under steady-state conditions, the rate of release of energy (power level) is proportional to reaction rate for a given fuel. In any given reactor these quantities are approximately proportional to average neutron flux and the quantity of fuel in the reactor.

reactivity
A measure of the departure of a reactor from critical, such that positive values of reactivity correspond to reactors above critical and negative values to reactors below critical. Often represented by (a) the multiplication constant minus one, (b) a quantity proportional to the inverse asymptotic period. Sometimes used interchangeably with the term *multiplication constant.*

reactor
An assembly capable of sustaining an appreciable nuclear reaction. **fission reactor** An assembly capable of sustaining a fission chain reaction. The term reactor may be modified by the words thermal, epithermal, intermediate, or fast to indicate the predominant energy of the neutrons causing fission. It may also be modified by the terms heterogeneous or homogeneous to characterize the detailed structure. The term reactor does not usually include the shield. *(See nuclear reactor)*

reboiler (chemical engineering)
The heat transfer equipment which generates vapor at the bottom of a continuous distillation unit. Also referred to as a kettle or still pot.

recessive character (genetics)
Of a pair of contrasted characteristics, the one which will not appear in the hybrid from cross-breeding homozygous parents unlike with respect to this characteristic.

recoil, aggregate
(See aggregate recoil)

recoil particle
A particle that has been set into motion by a collision or by a process involving the ejection of another particle. Examples are Compton recoil electrons, recoil nuclei in alpha decay, and fission fragments.

recombination
The return of an ionized atom or molecule to the neutral state.

recombination, coefficient of
A coefficient A that appears in the law expressing the rate of recombination of ions in a gas. If n^+ and n^- are the respective numbers per unit volume of the ions of the two signs,

then $$\frac{dn^+}{dt} = \frac{dn^-}{dt} = A\, n^- n^+.$$

recovery (metallurgy)
1. A process which usually precedes recrystallization when cold-worked metals are annealed. Residual stresses are partially relieved, but strength, ductility and grain structure remain substantially unchanged. Recovery is probably associated with elastic adjustments in individual grains.
2. In extractive metallurgy, the fraction of the valuable component which is obtained from an ore by processing.

(Radiology) The return toward normal of a particular cell, tissue, or organism after radiation injury. Recovery may apparently be complete, or it may be partial.

recovery rate (radiobiology)
The rate at which recovery takes place following radiation injury. It may proceed at different rates for different tissues. **differential recovery rate** Among tissues recovering at different rates those having slower rates will ultimately suffer greater damage from a series of successive irradiations. This differential effect is taken advantage of in fractionated *radiation therapy* if the neoplastic tissues have a slower recovery rate than surrounding normal structures.

recovery time (instrumentation)
The time interval, after the initiation of a count, which must elapse before a counter is capable of delivering at the next ionizing event a pulse of substantially full size.

recrystallization (metallurgy)
A process which occurs upon annealing cold-worked metals in which the original stressed and distorted grains are replaced by stress-free grains. The temperature of recrystallization depends upon the metal,

the extent of cold plastic deformation, the time of heating and the original grain size. The grain size after recrystallization depends primarily upon the amount of cold deformation, although it is influenced by temperature and time of annealing. The grain size resulting from recrystallization may be increased by further annealing to cause grain growth.

rectification
Any fractional distillation carried out in a distillation column. Sometimes restricted to that part of the process above the feed point. *(See enriching)*

rectifier (isotopes separation)
That section of a *cascade* between the feed point and product withdrawal point.

recycle
Any material or stream which is returned to an operation for further processing.

reference source
(See radioactive standard)

reflector (reactor engineering)
A layer or structure of material surrounding the core of a reactor to reduce the escape of neutrons. Neutrons entering the reflector are scattered randomly, some of them many times; and a large fraction of them ultimately may return to the core; it is possible to design a reflector by which more than ninety per cent of neutrons that would be lost may be returned *(see albedo)*. The requirements for a good reflector are in part the same as those for a good moderator; its atoms should have low neutron-absorption cross section and high scattering cross section. Low atomic mass is not important. The effectiveness of a reflector increases with its thickness, approaching a limiting value when the thickness is a few times the transport mean free path. A portion of a reactor between the shield and the core, introduced to return neutrons to the core. **reflector savings** A measure of the decrease in critical core size obtained by the use of the reflector.

reflux (chemical engineering)
The countercurrent recycle of a portion of an effluent.

reflux ratio
1. Quantity of reflux employed per unit quantity of overhead product removed.
2. The ratio of the rates of flow of the backward to the forward flowing streams in a counter-current system.

reflux ratio, minimum
The reflux ratio below which it is not possible to obtain the desired separation, even were an infinite number of stages used.

regeneration
The restoration or purification of contaminated nuclear fuel or other material to a usable condition.

regenerative process (biology)
The process by which damaged cells are replaced by new ones of the same type.

region of limited proportionality
The range of operating voltages for a counter tube below the Geiger threshold in which the gas amplification depends upon the number of ions produced in the initial ionizing event as well as on the voltage;

i.e., the counter is proportional for small initial events but saturates for larger ones.

regulating rod
A control rod intended to accomplish rapid, fine adjustment of the reactivity of a nuclear reactor. It usually is capable of moving much more rapidly than a shim rod but of making a smaller change in the reactor's reactivity. Its rapid and sometimes continuous readjustment may be accomplished by a servo system. (*See control rod; shim rod*)

relative abundance of an isotope
The fraction or percentage of the atoms of an element which constitute a given isotope. It usually refers to the natural isotopic mixture of an element.

relative aperture (accelerators)
vertical The ratio of the minimum vertical clearance for particle passage (in the accelerating chamber) to the particle orbit radius. **horizontal** The ratio of the minimum horizontal clearance for particle passage (in the accelerating chamber) to the particle orbit radius.

relative biological effectiveness of radiation (RBE) (radiobiology)
The inverse ratio of tissue doses of two different types of radiation that produce a particular biologic effect under otherwise identical conditions. In general the RBE may vary with the kind and degree of biological effect considered, the duration of the exposure, and other factors.

relative plateau slope (counter tubes)
The percentage change in counting rate per 100 volts increase of applied potential along the *plateau.*

relative stopping power
(See stopping power)

relative volatility (chemical engineering)
The quotient obtained when the ratio of the concentrations of any pair of substances in the vapor is divided by the ratio of the same pair of substances in the liquid with which the vapor is in equilibrium. It is a measure of the ease of separating the two components by distillation.

relativistic mass equation
The equation

$$m = m_o \left(1 - \frac{v^2}{c^2}\right)^{-1/2} = m_o/(1-\beta^2)^{1/2}$$

where $\beta \equiv v/c$ for the relativistic mass m of a particle or body of rest mass m_o when its velocity is v.

relativistic particle
A particle with a velocity so large that its relativistic mass exceeds its rest mass by an amount which is significant for the computation or other considerations at hand. *(See relativistic mass equation; relativistic velocity)*

relativistic velocity
A velocity sufficiently large that the values of some properties of a particle having this velocity are significantly different from the values of the same properties when the particle is at rest. The property of most interest is the mass. For many purposes, the velocity is relativistic when it exceeds about one-tenth the velocity of light. *(See relativistic particle; relativistic mass equation)*

relativity
A principle that postulates the equivalence of the description of the universe, in terms of physical laws, by various observers, or for various frames of reference. A theory that utilizes such a principle is called a **relativity theory.** An example is Einstein's **restricted theory of relativity,** in which the relativity principle applies to all inertial frames of reference. Two of the results of this theory of special interest in nuclear physics are (a) the *relativistic mass equation,* and (b) the principle of *mass-energy equivalence.*

relaxation time (isotopes separation)
The time required in a separating column or plant under given conditions for the mole fraction of the top stage to reach a specified fraction of the steady state value.

rem
(See roentgen equivalent, man)

rep
(See roentgen equivalent, physical)

reprocessing (reactor engineering)
Processing of material that is recovered after use in a reactor so that it may be used again. Reprocessing of uranium used in a reactor includes treatment to separate the plutonium formed, recover the uranium free of fission products and rework it into slugs or assemblies for return to the reactor.

reprocessing loss
Loss of fissionable, fertile, or other valuable materials, in reprocessing operations.

research reactor
(See nuclear reactor)

reservoir (isotopes separation)
Any volume, not otherwise essential to the process, incorporated in a separation plant or added to the separating device for the purpose of storing material or to insure smooth operation. In a fractional distilling column the distilling flask at the bottom acts as a reservoir, as does also the material contained in the overhead condenser.

residual activity
Radioactivity remaining in a substance or system at a specified time after a period of decay. In a nuclear reactor, the activity that remains when the reactor has been operated and then shut down.

residual range
(See range)

resolution (mass spectrometer)
The separation of adjacent peaks of a mass spectrum by a mass spectrometer.

resolving power (mass spectroscopy)
The highest value of the ratio $m/\Delta m$ for the complete separation of the mass spectrum lines differing by Δm in mass.

resolving time (counters)
The minimum time interval between two distinct events which will permit both to be counted. It may refer to an electronic circuit, to a mechanical indicating device, or to a counter tube.

resonance absorption (reactor theory)
The absorption of neutrons with energies corresponding to a nuclear

resonance level of the absorber. Sometimes used for absorption of all neutrons but thermal neutrons.

resonance capture
The capture of an incident particle into a *resonance level* of the resultant compound nucleus. Resonance capture is characterized by having a large probability *(cross section)* at and very close to the *resonance energy* involved, in comparison with energies somewhat removed from the resonance energy.

resonance energy
The kinetic energy, measured with reference to the laboratory system, of a particle that will be captured or scattered preferentially because of the presence of an appropriate *resonance level* in the compound nucleus (incident particle plus target nucleus). The relation of the resonance energy E_{res} to the energy of excitation E_{exc} of the resonance level above the ground state of the compound nucleus is given by the expression $E_{res} = (E_{exc} - E_B)$

$$\frac{\text{mass of compound nucleus}}{\text{mass of target nucleus}}$$ where

E_B is the binding energy of the incident particle in the compound nucleus.

resonance escape probability, p (reactor theory)
For a neutron slowing down without leakage, the resonance escape probability between two energies is the probability that a neutron at the higher energy will reach the lower energy rather than be absorbed.

resonance integral, ∫ (reactor theory)
1. The negative of the natural logarithm of the resonance escape probability multiplied by the slowing down power per atom of absorber. Sometimes applied to one of the approximate theoretical formulae used in its calculation.
2. The integral I, given by the equation

$$I = \int \frac{dE}{E} \left[\sigma(E) - \sigma(E_{th}) \left(\frac{E_{th}}{E} \right)^{1/2} \right]$$

This formula is valid only for substances which do not have resonances in the thermal region.

resonance level (nuclear)
An excited level of the compound system capable of being formed in a collision between two systems (e.g., between a nucleon and a nucleus). In a plot of cross section versus energy, there will usually be a maximum corresponding to each resonance level. *(See resonance energy)*

resonance neutrons
(See neutron)

resonance scattering
(See scattering)

rest mass, m_o
The mass of a particle at rest; symbol m_o. It is the mass in the classical, or Newtonian, sense; that is, it does not include the additional mass which, according to the *relativistic mass equation*, is acquired by a particle or body when set in motion.

retention
The fraction or percentage of radioactive atoms not separable from the target compounds or materials following the production of such atoms by nuclear reaction or radioactive decay.

rho meson
A term that was used for a short time to designate a *meson* which stopped in a nuclear emulsion, but apparently without any concomitant

decay event or nuclear interaction. Presumably most of the rho mesons actually were mu mesons, the decay event being unobserved because of insufficient sensitivity of the emulsion.

ring scaler (instrumentation)
A scaling circuit in which the asymmetrical condition is passed along to the next tube in line, with the last tube feeding back to the first. *(See scaler)*

r-meter
Any ionization instrument calibrated to read in roentgens.

Rockwell hardness
(See hardness)

rod
A relatively long and slender body of material used in or in conjunction with a nuclear reactor. It may contain fuel, absorber, or fertile material or other material in which activation or transmutation is desired. *(See fuel rod; absorption control; control rod)*

roentgen, r
The quantity of x- or gamma radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air, ions carrying 1 esu of electricity of either sign. *(See associated corpuscular emission)*

roentgen equivalent, man (rem)
The dose of any ionizing radiation that will produce the same biological effect as that produced by one roentgen of high voltage x-radiation. (A proposed unit, Parker)

roentgen equivalent, physical (rep)
A unit proposed to apply to statements of dose of ionizing radiation not covered by the definition of the roentgen. It has been variously defined as the dose which produces energy absorption of 83 ergs per gram of tissue or 93 ergs per gram of tissue. The actual energy absorption in tissue per roentgen is a function of the tissue composition and of the wavelength of the radiation, and ranges between 60 and 100 ergs per gram.
Various authors have used the term roentgen equivalent or equivalent roentgen, basing the equivalence on energy absorption by air, or on the number of ion pairs produced in air by one roentgen of x-rays, or on the energy absorption in tissue from one roentgen of x-rays, or on the ionization produced in a small air cavity by one roentgen of x-rays. The magnitude of all these units is the same within about 10 per cent, in terms of energy absorbed per gram of tissue. (A proposed unit, Parker)

roentgen rays
A synonym for *x-rays.*

roentgen therapy
Radiotherapy with x-rays.

roentgenography
Radiography by means of x-rays.

roentgenology
That part of radiology which pertains to x-rays.

rotation therapy
Radiation therapy during which either the patient is rotated before the source of radiation or the source is revolved around the patient. In this way, a larger dose is built up at the center of rotation within the patient's body than on any area of the skin.

Russell-Saunders coupling
(See coupling)

rutherford, rd

1. An unofficial unit for expressing the decay rate of radioactive material. It is a defined unit equal to 10^6 disintegrating atoms per second.
2. That amount of a substance undergoing 10^6 disintegrations per second.

(A proposed unit, Evans, Condon and Curtiss)

Rydberg constant, R
A constant given by

$$R = \frac{2\pi^2 m_e e^4}{ch^3}$$

that is especially useful in atomic spectroscopy. Since m_e is here the reduced mass of the electron, the value of R for a particular kind of atom is indicated by a subscript: R_∞ for a nucleus of infinite mass, R_H for hydrogen, R_{He} for helium, and so on. (See Table III)

TABLE III

Table of constants; least-squares adjusted output values.

N_o	Avogadro number $(6.02544 \pm 0.00011) \times 10^{23}$ $(\text{gm-mole})^{-1}$ (phys.)
c	Velocity of light (299790.2 ± 0.9) km sec^{-1}
$e = e'c$	Electronic charge $(4.80223 \pm 0.00007) \times 10^{-10}$ esu
m	Electron rest mass $(9.10721 \pm 0.00025) \times 10^{-28}$ gm
h	Planck constant $(6.62377 \pm 0.00018) \times 10^{-27}$ erg sec
λ_g/λ_s	Conversion factor from Siegbahn x-units to milliangstroms (1.002020 ± 0.000011)
$F' = Ne/c$	Faraday constant (9651.94 ± 0.07) emu mole^{-1} (phys.)
h/e	$(1.379311 \pm 0.000018) \times 10^{-17}$ erg sec esu^{-1}
$e/mc = e'/m$	Specific charge of the electron $(1.758897 \pm 0.000032) \times 10^{7}$ emu gm^{-1}
h/m	(7.27311 ± 0.00009) cm^2 sec^{-1} or erg sec gm^{-1}

$\alpha = 2\pi e^2 h^{-1} c^{-1}$	Fine structure constant $(7.29698 \pm 0.00005) \times 10^{-3}$
α^{-1}	137.0429 ± 0.0009
$k = R_o N^{-1}$	Boltzmann constant $(1.38026 \pm 0.000022) \times 10^{-16}$ erg deg^{-1}
$\mu_o = he'/(4\pi m)$	Bohr magneton $(0.927120 \pm 0.000022) \times$ 10^{-20} erg gauss^{-1}
$E_o = c^2 F'^{-1} 10^{-14}$	Conversion factor from atomic mass units to Mev (931.152 ± 0.008) Mev (amu)$^{-1}$ (phys.)
$E_g = c^2 e'^{-1} 10^{-14}$	Conversion factor from grams to Mev $(5.61060 \pm 0.00009) \times 10^{26}$ Mev gm^{-1}
$\lambda_{ce} = hm^{-1}c^{-1}$	Compton wavelength of electron $(2.426067 \pm 0.000032) \times$ 10^{-10} cm
Nm	Atomic weight of electron $(5.48749 \pm 0.00010) \times 10^{-4}$ (phys.)
$a_o = h^2(4\pi^2 me^2)^{-1}$	First Bohr radius $(5.29151 \pm 0.00003) \times 10^{-9}$ cm
$r_o = e^2 m^{-1} c^{-2}$	Classical radius of electron $(2.81751 \pm 0.00006) \times 10^{-13}$ cm
H	Atomic weight of hydrogen 1.0081284 ± 0.0000030 (phys.)
$H^+ = H - Nm$	Atomic weight of proton 1.0075797 ± 0.0000030 (phys.)
H^+/Nm	Ratio of proton mass to electron mass 1836.139 ± 0.034
R_∞	Rydberg for infinite mass (109737.323 ± 0.010) cm^{-1}

$R_H = (1 - Nm/H) R_\infty$	Rydberg for hydrogen (109677.591 ± 0.010) cm^{-1}
$\mu = mH^+/H$	Reduced mass of electron in hydrogen atom $(9.10225 \pm 0.00024) \times 10^{-28}$ gm
$E_e = c^3(e/m)^{-1}10^{-14}$	Energy equivalent of electron mass (0.510969 ± 0.000010) Mev electron mass^{-1}
$E_p = E_e H^+/Nm$	Energy equivalent of proton mass (938.210 ± 0.008) Mev proton^{-1}
$\lambda_{cp} = \lambda_{ce} Nm/H^+$	Compton wavelength of proton $(1.321287 \pm 0.000017) \times 10^{-13}$ cm
$\lambda_o = (hc^2e^{-1})10^{-8}$	Wavelength associated with 1 ev $(12396.44 \pm 0.17) \times 10^{-8}$ cm
$\nu_o = 10^8 e h^{-1} c^{-2}$	Wave number associated with 1 ev (8066.83 ± 0.11) cm^{-1}
$e10^8/c$	Energy associated with 1 ev $(1.601864 \pm 0.000024) \times 10^{-12}$ erg
$(F'/R_o) 10^8$	"Temperature" associated with 1 ev (11605.6 ± 0.5) deg Kelvin
$n_o = N/V_o$	Loschmidt number $(2.68744 \pm 0.00007) \times 10^{19}$ cm^{-3}

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S

S-50
The code name for the former liquid thermal diffusion separation plant at Oak Ridge, Tennessee.

safety rod
A control rod capable of shutting down a reactor very quickly in case of failure of the ordinary control system (e.g., regulating and shim rods). Since it must be able to reduce the reactor's effective multiplication constant to much less than unity when inserted, it is withdrawn almost completely during normal operation. A safety rod may be suspended above the core by a magnetic coupling and allowed to fall in if power reaches a predetermined level. (*See control rod; scram*)

sarcoma (biology)
Malignant *neoplasm* composed of cells imitating the appearance of the supportive and lymphatic tissues.

saturated activity
The maximum activity obtainable by activation in a definite flux. The saturated activity is proportional to the magnitude of the flux.

saturation
The condition which obtains when an induced nuclear reaction has continued sufficiently long to produce the asymptotic activity of a given radionuclide. In this condition the decay rate of the nuclide in question is equal to its rate of production. The approach of the activity toward saturation is described, in the case of direct production at a constant rate, by the equation

$$A = A_s(1-e^{-\lambda t})$$

where A is the activity at time t, A_s is the saturation activity and λ is the decay constant of the radionuclide.

saturation current
The ionization current which results when the applied potential is sufficient to collect all ions.

saturation voltage
The minimum value of applied potential required to produce saturation current.

scale of ten circuit
A decade *scaler.*

scale of two circuit
A binary *scaler.*

scaler, scaling circuit
A device that produces an output pulse whenever a prescribed number of input pulses have been received. The number of input pulses per output pulse of a scaling circuit is termed the scaling factor. A **binary scaler** is a scaler whose scaling factor is two. A **decade**

scaler is a scaler whose scaling factor is ten.

scalping (metallurgy)
The removal of the surface layers of metal ingots, billets, or slabs by machining or other means prior to fabrication.

scattered radiation (radiology)
Radiation which, during its passage through a substance, has been deviated in direction. It may also have been modified by an increase in wavelength.

scattering
The change in direction of a particle or photon owing to a collision with another particle or a system. (Reactor theory) Specifically, a collision of a neutron with a nucleus, such that after the collision the neutron and nucleus still exist as separate entities. In **elastic scattering,** the kinetic energy of neutron plus nucleus is unchanged by the collision, and the nucleus is left in the same state as before the collision; whereas in **inelastic scattering** the kinetic energy is decreased and the nucleus is left in an excited state. The angle between the initial and final lines of motion of a scattered particle is termed the **scattering angle,** which may be specified as applying either to the laboratory or center-of-mass frame of reference. The deflection of a particle from its original path owing to one encounter with a single scattering center in the material traversed is referred to as a **single scattering** event. This is to be distinguished from successive encounters with scattering centers, such as **plural scattering,** in which the final displacement is the vector sum of a small number of displacements. This may be regarded as a type intermediate between **single scattering** and **multiple scattering,** in which the final displacement is the vector sum of many, usually small, displacements. Scattering of particles or photons in which the scattering elements act independently of one another, so that there are no definite phase relationships among the different parts of the scattered beam, is termed **incoherent scattering.** Scattering of particles or photons in which there are definite phase relationships between the incoming and the scattered waves, is termed **coherent scattering.** In incoherent scattering the intensity of the scattered radiation at any point is obtained by adding the intensities of the scattered radiation reaching this point from the independent scattering elements. In coherent scattering, coherence manifests itself in the interference between the waves scattered by two or more scattering centers. Examples are the Bragg scattering of x-rays and of neutrons by the regularly spaced atoms in a crystal, for which constructive interference occurs only at definite angles, called *Bragg angles.* The part of nuclear scattering that has its origin in reflection from the nuclear surface, thus leaving the interior of the nucleus undisturbed, is termed **potential scattering.** The term usually is used in contradistinction to **resonance scattering,** which is the scattering arising from the part of the incident wave that penetrates the surface and interacts with the interior of the nucleus. In general, the scattered wave may have components arising from both kinds of scattering processes. Scattering of an incident wave by reflection at a change or discontinuity in the potential field, is also referred to as potential scattering. (*See back scatter*; *Bragg angle*; *cross section*; *collision*; *impact parameter*; *Mott scattering formula*; *self-scattering*; *Thomson scattering*)

scattering amplitude
A quantity closely related to the intensity of scattering of a wave by a central force field such as that of a nucleus. If e^{ikz} describes an incident plane wave of wave number k, then the scattered wave can be expressed as ae^{ikr}/r, at large distances r from the scattering center, where a is the scattering amplitude. The equation $\sigma = 4\pi|a|^2$ relates the scattering amplitude with the scattering cross section σ. These considerations hold for nuclear scattering at moderate energies (roughly below 10 Mev), where the scattering is symmetric in the center of gravity system. For higher energies the scattering may not be symmetric, and a must be generalized by expressing it in terms of Legendre polynomials in the *scattering* angle.

scattering angle
(See scattering)

scavenging (chemistry)
The use of an unspecific precipitate to remove from solution by adsorbtion or coprecipitation a large fraction of one or more undesirable radionuclides. Voluminous gelatinous precipitates are usually used as scavengers, e.g., $Fe(OH)_3$.

Schmidt lines, Schmidt limits
Two lines in the plot of nuclear magnetic moment versus nuclear spin that show the relationship to be expected according to the simple form of the *independent particle model*. For nuclides of odd atomic numbers Z, the magnetic moment of the odd proton can add or subtract from the magnetic moment arising from its orbital motion; addition determines the upper Schmidt line, and subtraction the lower Schmidt line. The two lines are approximately parallel, and show an increase in magnetic moment with increasing spin. For nuclides with an odd neutron, the lack of charge precludes any contribution to the magnetic moment from orbital motion. The Schmidt lines therefore are roughly parallel to the nuclear spin axis, and are spaced apart a distance corresponding to twice the neutron's magnetic moment. Experimentally, it is found that points describing actual nuclides do not lie on the Schmidt lines, but are scattered in the region between them.

scintillation
A flash of light produced in a phosphor by an ionizing event.

scintillation counter
The combination of phosphor, photomultiplier tube and associated circuits for counting scintillations.

scintillation spectrometer
A scintillation counter adapted to the study of energy distributions.

scleroscope hardness
(See hardness)

scram
Sudden shutting down of a nuclear reactor, usually by dropping of safety rods. This may be arranged to occur automatically at a predetermined neutron flux or under other dangerous conditions, the reaching of which causes the monitors and associated equipment to generate a scram signal. To shut down a reactor by causing a scram.

scram rod
Emergency *safety rod.*

screening (of nucleus)
The reduction of the electric field about a nucleus by the *space charge* of the surrounding electrons. The **screening constant,** or **screening number,** of an element is the atomic

number minus the apparent atomic number that is effective for a given process.

secondary circuit
(*See thermal cycle*)

secondary cosmic rays
(See cosmic rays)

secondary creep
(See creep)

secondary electron
(See electron)

secondary radiation
(See radiation, secondary)

secular radioactive equilibrium
(*See radioactive equilibrium*)

seed, radium
(See implant)

segregation (metallurgy)
A variation in the concentration of alloying elements or constituents of an alloy. On a micro-scale this variation may result in the production of dendrites composed of layers successively richer in one alloying element *(see coring)*. **Macrosegregation** refers to gross differences in concentration from one area to the next of an ingot. A variation in the composition of a casting caused by the settling of heavier constituents is called **gravity segregation.**

selection rules
A set of statements that serve to classify transitions of a given type (emission or absorption of radiation, beta decay, and so forth) in terms of quantum numbers of the initial and final states of the systems involved in the transitions in such a way that transitions of a given order of inherent probability (after making allowance for the influence of varying energy, charge and size of system, and so forth) are grouped together. The group having highest probability of taking place per unit time is said to consist of *allowed transitions;* all others are called *forbidden transitions.* Table IV lists the **selection rules for radiative transitions**: each entry gives the character (E = electric, M = magnetic) and the multipole order (1 for dipole, 2 for quadrupole, 3 for octopole,...) of the predominant radiation mechanism for the indicated spin change ΔI and parity change $\Delta \pi$; the entry "none" means that radiative transitions are strictly forbidden.

TABLE IV

ΔI / $\Delta \pi$	0 $I = 0$	0 $I \neq 0$	1	2	3	4	5
No	None	M1	M1	E2	M3	E4	M5
Yes	None	E1	E1	M2	E3	M4	E5

Table V lists the selection rules for beta decay: the entry A means that for the indicated spin and parity change the transition is allowed; I, means that it is first forbidden; II, second forbidden; . . . . .

TABLE V

ΔI / $\Delta \pi$	0	1	2	3	4	5	6
No	A	A	II	II	IV	IV	VI
Yes	I	I	I	III	III	V	V

Fermi selection rules and **Gamow-Teller (GT) selection rules** are alternative sets of rules for allowed beta transitions; both are currently believed to be valid, so that a transition allowed according to either set is actually allowed.

selective localization (isotopes)
In the use of radioisotopes, accumulation of a particular isotope to a

significantly greater degree in certain cells or tissues. *(See differential absorption ratio)*

self-absorption
The absorption of radiation by the body of the substance emitting the radiation. It reduces the radiation level against which further shielding must be provided. The absorption of radiation from a sample being assayed in the sample itself. Self-absorption is an important factor in the measurement of the activity of samples because the absorption by a thick sample will reduce the activity recorded by the instrument. Measured self-absorption effects necessarily include the effects of *self-scattering.*

self-energy
The energy equivalent of the rest mass of a particle. For example, the **electron self-energy** is $m_e c^2 = 0.511$ Mev, where m_e is the rest mass of the electron and c is the velocity of light.

self-quenched counter tube
A Geiger-Muller counter tube which is quenched by means of a suitable component in the counting gas.

self regulation
Stability of a nuclear reactor in which deviation from a certain power level affects reactivity so as to tend to restore power to the previous level without intervention of the control system. An example is the stability that may be associated with a reactor that has a negative temperature coefficient. *(See temperature coefficient; stability)*

self-scattering
The scattering of radioactive radiations by the body of the substance emitting the radiation. Self-scattering may outweigh self-absorption and may increase the measured activity over that expected for a weightless sample. *(Cf. self-absorption)*

self-shielding (reactor theory)
1. The shielding from neutrons arising outside the region of the inner portion of material by its outer portion.
2. The self-absorption of radiation by the source of radiation.

semiempirical mass formula
A *mass formula* (due principally to Weizsacker, Bethe, Bacher, Bohr and Wheeler) based on the *liquid-drop model of the nucleus.* It may be written:

$$M(A,Z) = ZM_H + (A - Z)\,M_n - aA + b\,\frac{(A-2Z)^2}{A} + 4\,\pi\,c r_o^2 A^{2/3} + \frac{3Z(Z-1)\,e^2}{5 r_o A^{1/3}} + \Delta.$$

Here $M(A,Z)$ is the mass of an atom of mass number A and atomic number Z, M_H and M_n are the masses of the hydrogen atom and the neutron, e is the electronic charge, r_o is the radius parameter (*see radius, nuclear*), and a, b and c are adjustable parameters. The terms represent, in order: the mass of the constituent protons and electrons; the mass of the constituent neutrons; the "bulk energy of condensation" due to short-range attractive forces between nucleons; the "asymmetry energy" corresponding to the tendency of protons and neutrons to be equal in number; the "surface energy"; the "electrostatic energy" due to repulsive forces between protons; and the "pairing energy" as given under *empirical mass formula.*

sensitive time
The duration of supersaturation adequate for track formation following expansion of a cloud chamber.

sensitive volume
That portion of a counter tube or ionization chamber which responds to a specific radiation. (Radiobiology) Part of a cell (sensitive region) particularly sensitive to radiation. (*See target theory*)

separation
(See Szilard-Chalmers method)

separation energy
A synonym for *binding energy* of a proton, neutron, or alpha particle.

separation factor
The ratio of the *abundance ratio* of two isotopes after processing to their abundance ratio before processing. It is given by the following equation:

$$r = \frac{n'_1/n'_2}{n_1/n_2}$$

where n_1 and n_2 are the mole fractions of isotopes of mass numbers m_1 and m_2 respectively, and n'_1 and n'_2 are the corresponding quantities after processing. The term *enrichment factor* is sometimes used for $r - 1$.

separation of isotopes
centrifuge A method in which a mixture of isotopes in the gaseous or liquid state is caused to spin at high speeds. The radial forces, which are very high compared to ordinary gravitational forces, cause an increase in concentration of the heavier isotopes near the periphery and correspondingly an increase in concentration of the lighter isotopes near the axis of the chamber. **diffusion pumps** An application of the process of separation by diffusion through a gas, in which a gaseous isotopic mixture diffuses through a vapor stream into the jet of a diffusion pump. The lighter molecules are pumped preferentially by the streaming vapor, producing a separation effect. **diffusion through gas** A method in which a gas that is an isotopic mixture is allowed to diffuse through another (preferably heavier) gas. Separation of the various isotopes is based on the principle that the lighter isotopic molecules diffuse through the heavier gas more readily than the heavier isotopic molecules. The ideal simple process factor is

$$\alpha = \frac{M_2}{M_1}\left(\frac{M_1 + M_3}{M_2 + M_3}\right)$$

where M_1 and M_2 are the masses of the isotopic molecules, and M_3 the mass of the heavy gas. **electrolysis** The separation of isotopes by electrolytic decomposition of a solution, as in the electrolysis of water for the concentration of deuterium. The method depends on the differing rates of discharge of isotopic ions, and hence is a function of the chemical properties of the different isotopes. **electromagnetic method** A separation of ions of varying mass by a combination of electric and magnetic fields. In the most common application an isotopic mixture of ions is produced either by electron bombardment of a gas or by thermionic emission. The ionized particles are accelerated and collimated into a beam by a system of electrodes, and the beam is projected into a magnetic field where the paths of the ions depend on their mass-to-charge ratio. Properly located collectors can be placed to receive ions of specified masses. The foregoing method is based on the principle of the mass spectograph. **fractional distillation** A method whereby isotopes in liquid form are separated in a fractionating tower by evaporation and re-condensation. The distillation process results in an upward-directed stream of vapor and a downward-directed stream of liquid, the two being in intimate contact and constantly exchanging molecules. **gaseous diffusion through a barrier** A method in which a gas that is an isotopic mixture is allowed to diffuse through a porous wall or barrier. Separation of the various isotopes is based on the principle that the lighter molecules, M_1, diffuse through the porous wall more readily than the heavier molecules, M_2. The effective simple process factor is generally less than $a = \sqrt{M_2/M_1}$ because of insufficiently long mean free path, back diffusion, impoverishment of gas in front of the barrier (cut correction, mixing inefficiency), etc. **ion mobility** A process based on the difference in mobility of different ions in an electrolytic solution under the influence of an electric field. **thermal diffusion** A method based on the observation that in many mixtures a temperature gradient causes the concentration of one type of molecule in the warmer region and of the other type in the colder region. In the Clusius column a temperature gradient is established between two concentric vertical cylinders, and the counter-current circulation set up by thermal convection produces a cascading effect. Either a gas or liquid may be employed as the working medium. (*See Clusius column*)

separation potential
(See value)

separation process
1. A chemical process for the isolation and decontamination of a given radioelement from a mixture in which it occurs or in which it may have been formed by nuclear transformation.
2. A physical or chemical process resulting in the isolation of a product containing one or more elements of isotopic composition appreciably different from that in the starting material.

separative element (isotopes separation)
Any separative unit, such as an individual centrifuge, a fractionating tower or a single plate of a fractionating tower, a calutron, or a single source and receiver of a calutron, a diffuser unit or a fixed area of diffusing surface, which may be considered to be the basic element of a large apparatus containing many similar units.

separative power
A measure of the useful amount of separation accomplished in unit time by a *separative element.* It is proportional to the circulation which can be handled and, for separation factors only slightly greater than one, to the square of the excess over unity of the effective simple process factor.

series
(See radioactive series)

series decay, disintegration
(See radioactive series)

servo system (reactor engineering)
An automatic control system for maintaining a process condition (e.g., the power level of a nuclear reactor) at or near a predetermined value by activation of an element such as a control rod. It compares the required condition (desired value) with the actual condition, adjusting the control element in accordance with the difference and (sometimes) the rate of change of the difference.

sex linkage (biology)
The inheritance of certain characteristics which are determined by genes located on the sex chromosomes.

shell (of nucleus)
(See nucleus, shell model of; nucleus, shell structure of)

shield (reactor engineering)
A body of material used to prevent or reduce the passage of particles or radiation. A shield may be designated according to what it is intended to absorb, as a gamma-ray shield or neutron shield, or according to the kind of protection it is intended to give, as a background, biological, or thermal shield. The shield of a nuclear reactor is a body of material surrounding the reactor to prevent the escape of neutrons and radiation into a protected area, which frequently is the entire space external to the reactor. It may be required for the safety of personnel or to reduce radiation sufficiently to allow use of counting instruments for research or for locating contamination or airborne radioactivity. *(See biological shield; concrete; thermal shield)*

shielding
The arrangement of shields provided for any particular circumstances or establishment. The use of shields.

shim rod (reactor engineering)
A control rod used for making occasional coarse adjustments in the reactivity of a nuclear reactor. It commonly moves more slowly than a 'regulating rod and, singly or as one of a group, is capable of making a greater total change in the reactivity. Its name is derived from analogy to a mechanical shim; a shim rod commonly is positioned so that the reactor will be just critical (reactivity = 0, effective multiplication constant = 1) when the regulating rod is near the middle of its range of travel. *(See control rod.)*

shimming (instrumentation)
The adjustment of a magnetic field to achieve desired characteristics by means of thin spacers, shims of soft iron, or compensating coils.

shower
(See cascade shower; cosmic rays; extensive shower; penetrating shower)

shower unit (cosmic rays)
The mean path length required for the reduction, by the factor 1/2, of the energy of relativistic charged particles as they pass through matter. Such particles lose their energy mostly by radiation *(see bremsstrahlung)*. The shower unit s is related to the *radiation length* l by the equation:

$$s = l \ln 2 = 0.693\, l$$

shrinkage cavity (metallurgy)
A void in cast metals which results from the contraction due to solidification and the progressive freezing towards the center of a pocket of liquid.

shut-down
Procedure of stopping a chain reaction by bringing the reactor to a subcritical condition (effective multiplication constant less than 1). State of a reactor after being shut down.

shut-down procedure
Sequence of operations used for shutting down a nuclear reactor. It includes reducing the effective multiplication constant to less than unity by insertion of safety rods or the equivalent and, usually, reducing the flow of coolant to the amount required for removing the heat of residual activity.

shutter (reactor engineering)
1. A movable plate of absorbing material (e.g., boron, lead, or

other material, depending on whether neutron or gamma radiation is involved) used to cover a window or beam hole when radiation is not desired.
2. A thin shield made up of movable shutter-like elements, usually cadmium, used to shut off a flow of slow neutrons.

shuttle
(See rabbit)

side stream
A stream withdrawn from some point along the height of a distillation tower.

sieve plate
In a distillation column, a tray or plate containing numerous perforations which permit upward vapor and downward liquid flow. An overflow pipe is provided to prevent excessive liquid accumulation on the plate.

sigma meson
A term that was used for a short time to designate a meson which produces a *star*. These mesons were soon identified as pi *mesons* (predominantly negative).

sigma pile (reactor theory)
An assembly of a moderating material containing a neutron source, used in the study of the neutron properties of the material.

sigmoid curve
S-shaped curve, often characteristic of a *dose-effect curve* in radiobiological studies.

simple distillation
A distillation in which the vapor evolved from the boiling liquid is removed as fast as it is formed without the return of condensed vapor to the boiling liquid.

simple process factor
The enrichment factor obtained in a single process such as a simple distillation or a single pass through a diffusing barrier, or a single pass in a calutron. The actual separation factor obtained by a real separative element is termed the **effective simple process factor.** Generally speaking, the **ideal simple process factor** is the theoretically greatest possible equilibrium enrichment factor for the elementary process considered, under idealized conditions. Thus for diffusion of a binary mixture through barriers, the ideal simple process factor α is

$$\alpha = \sqrt{M_2/M_1}$$

where M_1 is the molecular weight of the lighter gas, and M_2 is the molecular weight of the heavier gas.

single particle model of nucleus
A synonym for *independent particle model of nucleus.*

single scattering
(See scattering)

single-stage recycle (isotopes separation)
An adaptation of the gaseous diffusion principle wherein the diffusing gas is separated into two fractions, one of which is advanced to the next stage while the other is re-circulated within the original stage; sometimes called *rabbit.*

sintering
The process of bonding metal or other powders by heating to form a strong cohesive body. The powders are usually first cold pressed into the desired shape. Sintering is usually accompanied by a considerable reduction in volume.

skin dose
(See dose, skin)

slip (metallurgy)
A process of plastic deformation of metals by the simple shear displacement of one part of a crystal relative to another.

slip stream
(See side stream)

slow neutrons
1. Neutrons having kinetic energies up to about 10^2 ev.
2. Loosely used as a synonym for *thermal neutrons.*

slow reactor
A nuclear reactor in which fission is induced primarily by slow neutrons. In practical cases, these are of thermal energy. Hence, commonly, thermal reactor. *(See nuclear reactor)*

slowing-down
Decrease in energy of a particle.

slowing-down area
In an infinite homogeneous medium, one-sixth the mean square distance between the neutron source and the point where the neutron reaches a given energy. In Fermi theory, the *age.*

slowing-down density
At a given energy and time, the number of neutrons per unit volume per unit time which are going from an energy greater than the given energy to a lower energy.

slowing-down length
The square root of the *slowing-down area.*

slowing-down power
The average loss in natural logarithm of energy (average increase in *lethargy*) of a neutron per unit distance traveled by the neutron in the substance.

slug
A lump of nuclear fuel, commonly in the form of a short round bar, or cylinder, to be inserted into holes or channels in the active lattice of a reactor. Slugs commonly are encased in *jackets.* The term often refers to the fuel of a natural uranium-graphite reactor.

slurry reactor
A nuclear reactor having the fissionable material in a semifluid form, e.g., a slurry of particles suspended in liquid.

sodium (Na)
A metallic element, eleventh in the atomic series, with melting point 97.5 °C and moderate thermal neutron cross section. It has been suggested for use as a liquid-metal heat-transfer fluid.

soft component of cosmic rays
That portion of cosmic radiation which is absorbed in a moderate thickness of an absorber (usually 10 cm of lead). It consists mainly of electrons, positrons, and photons, but contains some slow mesons, slow protons, and other heavy particles often present in cosmic radiation. *(See cosmic rays)*

soldering
(See brazing)

solid solution (metallurgy)
A single phase solid containing more than one component. A **substitutional solid solution** is one in which the solute atoms replace solvent atoms. In **interstitial solid solutions,** the solute atoms are found in the space among the solvent atoms. In general, the solute atoms in the latter case are much smaller than those of the solvent, while in substitutional solid solutions the atoms do not differ greatly in size.

Elements which are completely soluble in all proportions in the solid state form a continuous series of solid solutions, and this occurs only when the elements are chemically similar and possess nearly identical atomic diameters and the same crystal structure. **Terminal solid solutions** are those in which a pure element is the solvent. **Intermediate solid solutions** are separated in the phase diagram from the pure elements or terminal solid solutions by multiphase regions.

somatic cells (biology)
Body cells, usually having two sets of chromosomes, as opposed to *germ cells.*

soret effect
An alternative term for the phenomenon of *thermal diffusion.*

source range (reactor operation)
Low-power range of operation in which the reactor is subcritical and its power depends upon its multiplying the neutron flux from an added source. (*See multiplication; neutron source)*

space charge
The electric charge carried by a cloud or stream of electrons or ions in a vacuum or a region of low gas pressure, when the charge is sufficient to produce local changes in the potential distribution. It is of importance in thermionic tubes, photoelectric cells, ion accelerators, and so on.

space-charge-limited operation
A condition of operation of an electromagnetic separator under which optimum focusing of the ion beam is lost due to *space charge,* i.e., the repulsion of an excess of like charges in the beam.

spallation (nuclear physics)
A term used to denote a nuclear reaction induced by high energy bombardment and involving the ejection of more than two or three particles (neutrons, protons, deuterons, alpha particles, etc.). It is often not known by what path or paths the reaction proceeds, and therefore the production by spallation of a nuclide $_{Z'}Q^{A}$ from the target nuclide $_{Z}P^{A}$ is often written as

$$_{Z}P^{A}(_{Z''}R^{A''},\ xz\ ya)_{Z'}Q^{A'}$$

where $_{Z''}R^{A''}$ is the bombarding particle and

$$x = Z + Z'' - Z',\ y = A + A'' - A'.$$

With bombarding energies of several hundred Mev, values of x and y as high as 20 or 30 have been reported. Examples of spallation are: $Bi^{209} + He^{4} \longrightarrow At^{210} + 3n$; $As^{75} + H^{2} \longrightarrow Mn^{52} +$ unknown fragments. The abbreviated symbolism for these reactions is: $Bi^{209}(\alpha, 3n)At^{210}$; $As^{75}(d, 9z25A)Mn^{52}$. In the second example, where the kind and number of **spallation fragments** is not known, there is recorded merely the decrease in atomic number and mass numbers of the hypothetical compound *nucleus.*

spalling (metallurgy)
Flaking of the surface of metals or refractories leaving new surfaces exposed. Spalling is due to localized stresses, frequently thermal stresses.

sparging
Introduction of a gas or vapor beneath the surface of a liquid for the purpose of agitation, heat transfer or stripping.

specific activity

1. The *activity* of a radioisotope of an element per unit weight of element present in the sample.
2. The activity per unit mass of a pure radionuclide.
3. The activity per unit weight of any sample of radioactive material. *Note:* Specific activity is commonly given in a wide variety of units (e.g., millicuries per gram, disintegrations per second per milligram, counts per minute per milligram, etc.). Examples: **specific activity, element, specific activity, isotope,** total radioactivity of a given isotope per gram of the radioactive isotope.

specific electronic charge

The ratio e/m_e of the electronic charge to the rest mass of the electron; $e/m_e = 1.759 \times 10^7$ abcoul gm^{-1}.

specific ionization

The number of ion pairs formed per unit distance along the track of an ion passing through matter. This is sometimes called the **total specific ionization** to distinguish it from the **primary specific ionization,** which is the number of **ion clusters** produced per unit track length. The **relative specific ionization** is the specific ionization for a particle in a given medium relative either to that for (i) the same particle and energy in a standard medium, such as air at 15 °C and 1 atm, or (ii) the same particle and medium at a specified energy, such as the energy for which the specific ionization is a maximum. (*See ion; minimum ionization*) A **specific ionization curve** shows the average specific *ionization* of an ionizing particle of a particular kind as a function of its kinetic energy, velocity, or residual range. (figs. 6 and 7)

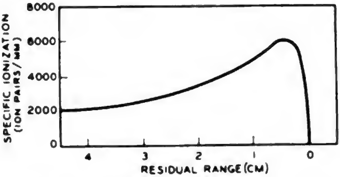

Fig. 6 Specific ionization curve for low energy alpha particles in dry air at 15 °C and 1 atm.

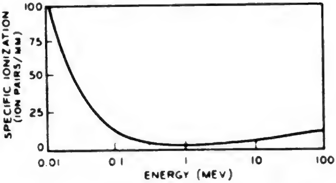

Fig. 7 Specific ionization curve for electrons in dry air at 15 °C and 1 atm.

specific ionization of a particle

The number of ion pairs per unit path length. (*See specific ionization*)

specific power

Power produced per unit mass of fuel present in a reactor. Specific power usually is based upon the fuel actually present but may be based upon the total investment, including fuel undergoing reprocessing.

spectrometer

(*See gamma ray spectrometer; mass spectrometer*)

spectrum

A visual display, a photographic record, or a plot of the distribution of the intensity of radiation of a given kind as a function of its wavelength, energy, frequency, momentum, mass, or any related quantity. Severally distinguished as: **line spectrum** A spectrum produced by radiation in which the energy values of the property being measured (such as energy, mass, or any related quantity) cluster about one or more discrete values, as contrasted with a continuous spectrum. A group of monoenergetic radiations results from identical quantum transitions of identical emitting systems. There is always a spread of energies about a mean value, giving a finite width to each line of the hypothetical perfect spectrum. (*See line width*) Often, however, the actual width of a spectral line is increased still more because of instrumental imperfections. **band spectrum**. A spectrum giving the appearance of bands, usually found in spectra of molecules. In nuclear physics, band spectra are useful in determining nuclear spin and statistics, and isotopic abundances. **continuous spectrum** (1) For electromagnetic radiation, a spectrum that exhibits no detailed structure and. represents a gradual variation of intensity with wavelength from one end to the other. Examples are the spectrum of light from an incandescent solid and the continuous x-ray spectrum. (2) For particles, a spectrum that exhibits a continuous variation of the momentum or energy. The beta-ray spectrum definition is an example. **mass spectrum** A spectrum showing the distribution in mass or in mass-to-charge ratio of ionized atoms, molecules, or molecular fragments. The mass spectrum of an element shows the *relative abundances* of the isotopes of the element. The mass spectrum of a compound is quite complicated and not easily related to the relative abundances of the various kinds of atoms and groups present; however, under given experimental conditions it is characteristic of the compound and often useful for identification and assay. (*See mass spectograph*; *mass spectrometer*) **alpha-particle spectrum** The distribution in energy or momentum of the alpha particles emitted by a pure radionuclide, or, less commonly, by a mixture of radionuclides. Each alpha-emitting nuclide yields a characteristic spectrum consisting of one or more sharp lines, each line being due to a particular group of monoenergetic particles. When more than one group is present, the distribution is said to have **fine structure**; this results from transitions to more than one nuclear energy state of the product nuclide, the group of highest energy coming from the ground-state transition. In exceptional cases (RaC′ and ThC′), lines are observed due to groups that have very low intensities (10^{-6} to 10^{-4}) relative to those for the main groups. The particles producing such lines are called **long-range alpha particles.** They result when the emitting nuclei are formed in excited states in the preceding beta disintegration (of RaC or ThC) and emit alpha particles directly from the excited states, instead of becoming de-excited by the more usual gamma emission. The normal alpha disintegration energy is then augmented by the excitation energy. **beta-ray spectrum** (1) The distribution in energy or momentum of the beta particles (not including conversion electrons) emitted in a beta-decay process. The beta-ray spectrum is always continuous up to a maximum energy. Its shape depends upon the nature of the particular beta-decay process. (2) Sometimes, and loosely, the energy spectrum of the electrons emitted by a radioactive source, irrespective of their origin. In addition to the continuous spectrum of definition (1), it may show lines due to *internal conversion* or to Auger electrons. (*See Auger effect*) **continuous x-rays; continuous x-radiation** The electromagnetic radiation of continuous spectral distribution produced by *bremsstrahlung*, for example, when electrons strike a target. The wavelengths of the continuous x-rays vary from a minimum, corresponding to a photon energy equal to the maximum kinetic energy of the incident particles, to indefinitely large values. For a given tube current, the intensity associated with each wavelength is dependent on the material and thickness of the target, and on the potential difference applied to the tube. The continuous spectrum produced by very high-velocity electrons from, say, a betatron, may extend into or beyond the gamma-ray range of wavelengths. However, such radiation is still referred to as *x-rays,* the term *gamma rays* being reserved for electromagnetic radiation emitted by nuclei. **characteristic x-rays** Electromagnetic radiation emitted as a result of rearrangements of the electrons in the inner shells of atoms. The spectrum of the radiation consists of lines that are characteristic of the element in which the x-rays are produced. The energies of the lines are in general grouped in comparatively simple and similar series known as the K-series, the L-series, and the M-series, although for elements of atomic number less than about 20, the electron shells may not be complete enough to permit extensive development of all of these series. The wavelengths are mainly in the range from about 0.1 to 10 Å, although for very light elements they become so long as to merge into the ultraviolet. The target of an x-ray tube will in general emit both continuous x-rays, due to *bremsstrahlung*, and (when the tube voltage is high enough) characteristic x-rays associated with the target material. (*See fluorescence*)

spermatogenesis (biology)
The successive divisions which transform the spermatogonium into the mature spermatozoon.

spin
(See angular momentum)

spin-orbit coupling
(See coupling)

spin quantum numbers
(See angular momentum)

spinthariscope
An instrument in which scintillations are visually observed through a microscope.

spleen (biology)
A large gland-like organ, one function of which is to disintegrate the red blood corpuscles and release hemoglobin.

split-flow reactor
A reactor in which the coolant enters at the center section and flows outward at both ends or vice versa.

spray points
A row of sharp points charged to a high d-c potential, the purpose of which is to charge and discharge the conveyor belt in a *Van de Graaff generator.*

spring-back (metallurgy)
An indication of unbalanced residual stresses frequently measured as the increase in diameter of a tightly wound coil which is permitted to unwind, or the increase in dimensions of a pressed piece upon removal from a die. The change in spring-back on annealing may be employed as a measure of the recovery which precedes recrystallization.

spurious counts
Counts caused by imperfections of the counter.

square cascade
(See cascade, square)

stability (reactor engineering)
A tendency to hold a steady power level without action by the control system. *(See self regulation; temperature coefficient)* A **stable control system** is one that holds the process condition under its regulation at the desired level without drift or hunting. *(See thermal instability)*

stable (atomic or nuclear system)
Incapable of spontaneous changes. A stable nuclide is one that is not radioactive. The term is sometimes applied to nuclides for which radioactive transformations would be energetically possible, but are so highly forbidden as to result in radioactivity too feeble to detect by currently available techniques; thus nuclides with lifetimes exceeding about 10^{15} to 10^{18} yr would be considered stable at present. The term may be qualified to indicate incapability of a specified mode of spontaneous change; for example, **beta stable** means incapable of ordinary beta disintegration, although possibly capable of alpha disintegration, double-beta disintegration, isomeric transition, or spontaneous fission.

stable isotope
(See isotope, stable)

stable orbit (betatron, synchrotron)
The circle of constant radius described by accelerated particles.

stage (cascade)
A stage of a cascade consists of units operating in parallel on material of the same concentration.

stages, minimum number of theoretical
The number of theoretical stages below which it is not possible to obtain the desired separation of a mixture as, for example, in a continuous distillation.

star (nuclear)
A group of tracks due to ionizing particles originating at a common point, either in a *nuclear emulsion* or in a cloud chamber, so named because of its appearance. Some stars are produced by successive disintegrations of an atom in a radioactive series; others, by nuclear reactions of the *spallation* type, for example, by cosmic-ray particles. *(See spallation)*

start-up procedure
Specific procedure for bringing a given nuclear reactor into operation at a desired power level. This may include establishing flow of coolant, starting reaction in the counter range, increasing reaction in the counter range, increasing control, and leveling off at the reaction rate into the instrument range, approaching criticality and shifting from manual to automatic required power. *(See counter range; instrument range; power range)*

starting voltage
For a counter tube, the minimum voltage that must be applied to obtain counts with the particular circuit with which it is associated.

static multipole moments
(See multipole moments)

statistical error
Errors in counting due to the random time-distributions of disintegrations.

statistical straggling
(See straggling)

statistics
(See quantum statistics)

steam distillation
A distillation in which vaporization of the volatile constituents is effected at a temperature lower than the normal boiling point by the introduction of steam directly into the charge.

steel
Iron alloyed with carbon and other elements. It is important as a structural and mechanical material in reactors but must be used sparingly in the active section of a thermal reactor both because of its absorption of thermal neutrons and because some of its constituent elements, on capturing neutrons, become strongly radioactive with such long half-lives as to cause serious handling problems if the steel parts must be removed in reloading or maintenance. Outside the active section, however, it is useful in both neutron and thermal shields. *(See thermal shield)*

stem radiation (roentgenology)
X-rays given off from parts of the anode other than the target; in particular, from the target support.

step (reactor engineering)
An off-set in the side of a hole through a shield or in the corresponding plug or other closure, provided so that when the hole is closed the mating steps on the hole and plug will form a zig-zag joint and avoid leaving a straight crack through the shield, along which radiation might escape more readily.

sterility (biology)
Temporary or permanent inability to breed.

still
Any apparatus in which a substance is vaporized and the vapors are condensed; sometimes refers to the vaporizing section only. *(See distillation)*

stopping
The decrease in kinetic energy of an ionizing particle as a result of energy losses along its path through matter.

stopping cross section
A synonym for atomic stopping power. *(See stopping power)*

stopping equivalent
(See stopping power)

stopping power
A measure of the effect of a substance upon the kinetic energy of a charged particle passing through it. The **linear stopping power** S_l is the energy loss per unit distance, and is given by $S_l = -dE/dx$, where E is the kinetic energy of the particle and x is the distance traversed in the medium. The **mass stopping power** S_m is the energy loss per unit surface density traversed, and is given by $S_m = S_l/\rho$, where ρ is the density of the substance. The **atomic stopping power** S_a of an element is the energy loss per atom, per unit area normal to the particle's motion, and is given by $S_a = S_l/n = S_m A/N$; where n is the number of atoms per unit volume, N is the Avogadro number, and A is the atomic weight. The **molecular stopping power** of a compound is similarly defined in terms of molecules; it is very nearly if not exactly equal to the sum of the atomic stopping powers of the constituent atoms. The **relative stopping power** is the ratio of the stopping power of a given substance to that of a standard substance, commonly aluminum, oxygen or air. The **stopping equivalent** for a given thickness of a substance is that thickness of a standard substance capable of producing the same energy loss. The **air equivalent** is the stopping equivalent in terms of air at 15 °C and 1 atm as the standard substance. The term **equivalent stopping power** is not clearly defined, but sometimes is used synonymously with relative stopping power and sometimes with stopping equivalent.

stored energy
(See energy, stored)

straggling
The random variation or fluctuation of a property associated with ions

of a given kind in passing through matter. **Range straggling** is the variation in the range of particles that are all of the same initial energy. **Angle straggling** is the variation in the direction of motion of particles after passing through a certain thickness of matter, the paths of the particles initially being parallel. **Statistical straggling** is that variation in range, ionization or direction which is due to fluctuations in the distance between collisions in the stopping medium and in the energy loss and deflection angle per collision. If the energy loss and deflection angle per collision are small, as they are for alpha particles and similar heavy ions of small charge, the number $N(R)\,dR$ of particles having ranges between R and $R + dR$ is given approximately by an expression having the form of the normal probability distribution:

$$N(R)\,dR = \frac{N_o}{\sqrt{\pi}\,a}\, e^{-\left(\frac{R-R_o}{a}\right)^2}\, dR$$

where N_0 is the total number of particles, R_0 is the *mean range*, and a, which is called the **straggling parameter,** is equal approximately to 1 or 2 per cent of the range for radioactive alpha particles. A similar formula applies to ionization straggling, the value of a here being about 0.5 per cent of the total ionization. **Instrumental straggling** is that additional straggling which is due to such instrumental effects as noise, gain instability, source thickness, and poor geometry.

strain hardening
An increase in hardness and strength of metals caused by plastic deformation.

stratigraphic age
(See age)

stray radiation
Radiation not serving any useful purpose. It includes *direct radiation* and secondary radiation from irradiated objects.

streamline flow
Fluid flow such that the local velocity of the fluid medium is steady in both direction and magnitude.

stress-to-rupture (metallurgy)
A type of high-temperature test in which the stress required to cause rupture in a stated time is determined. For each temperature of interest, a series of tests is made over a range of stresses selected to cause rupture in times of a few hours to several thousand hours. The data from these tests are usually reported as stresses to produce rupture in 10, 100, and 1000 hours, accompanied by the elongations at rupture.

stringer
A long structure occupying a hole through the shield and sometimes into the active section of a *nuclear reactor.* Removal of the stringer permits access to the core for inserting experimental materials. If it is part of a large graphite reactor, for instance, part of its length may consist of graphite blocks keyed together so as to be withdrawn as a unit.

stripper
That section of a *cascade* between the feed point and the waste-withdrawal point. Essentially it strips desired isotope from the waste stream.

stripping (nucleonics)
An effect observed in bombardment with deuterons or heavier nuclei, whereby only part of the incident particle merges with the target nucleus, and the remainder proceeds with most of its original momentum in practically its original direction.

The effect is strongly marked in deuteron bombardment, and in this case typically leads to directional neutron and proton beams that emerge from the target (if the latter is sufficiently thin) predominantly in the forward direction. The angular divergence of the beams decreases with increasing energy of the incident deuterons. Subsidiary peaks are sometimes observed at rather small angles relative to the forward direction. When the (d,p) type of stripping occurs with deuterons having energies smaller than or comparable with the Coulomb barrier of the target nucleus, it is often called the *Oppenheimer-Phillips process.*

(Chemical engineering)

1. The removal of a component from a solid or liquid by contact with a gas or vapor.
2. The removal of solute from a solvent by extraction into another solvent usually employed in large excess.
3. Fractional distillation carried out below the feed point of a distillation column.

strontium age
(See age)

subcritical (reactor)
Having an effective multiplication constant less than one, so that a self-supporting chain reaction cannot be maintained.

supercritical (reactor)
Having an effective multiplication constant greater than one, so that the rate of reaction rises.

superficial velocity (chemical engineering)
The flow rate through a tower or other process equipment based on the over-all cross section, neglecting the cross-sectional area blocked by internal obstacles. The flow rate can be expressed either in mass or volumetric units.

supervoltage (radiology)
A term applied to radiation generated by x-ray tubes operating at voltages in the range from 500 to 2000 kv.

surface density (nuclear physics)
The quantity per unit area of anything distributed over a surface. Examples are electric charge per unit area and mass per unit area. It is in the latter sense that the term is used in nuclear physics, this being a common way of indicating an absorber thickness, source thickness, target thickness, support thickness for thin radioactive sources, and so on.

surface tension, nuclear
(See liquid-drop model of nucleus)

survey instrument (radiation)
A portable instrument, used for detecting and measuring radiation under varied physical conditions. The term covers a wide range of devices utilizing most of the detection methods defined elsewhere.

survival curve (radiobiology)

1. Curve obtained by plotting number or percentage of organisms surviving at a given time against dose of radiation.
2. Curve showing percentage of individuals surviving at different intervals after a particular dose of radiation.

synchro-cyclotron, f-m cyclotron
A cyclotron in which the radiofrequency of the electric field is frequency-modulated to permit the acceleration of particles to relativistic energies.

synchrotron
A device for accelerating particles, ordinarily electrons, in a circular orbit in an increasing magnetic field by means of an alternating electric

field applied in synchronism with the orbital motion. A **proton-synchrotron** is a synchrotron modified to permit the acceleration of protons by frequency modulation of the radiofrequency accelerating voltage.

syndrome (biology)
The complex of symptoms associated with any disease.

systemic reaction (biology)
Generalized reaction of the whole body, rather than localized reaction.

Szilard-Chalmers method
A chemical method for the separation, in increased specific activity, of a radionuclide from isotopic target material following nuclear reactions which do not result in a change of Z, such as (n, γ), (n, $2n$), (γ, n), (d, p). The method is based on the fact that, as a result of such nuclear reactions (for example, due to the γ-ray recoil in an n, γ process), the radioactive atoms are often ejected from molecules and can therefore frequently be separated in a chemical form different from that of the target material.

T

T, t
(See tritium and triton)

tagged atom
The atomic position in a molecule which is distinguished by an isotopic tracer. **tagged atoms** Atoms of an isotopic tracer. (*See tracer, isotopic*)

tamper
The reflector associated with a nuclear reactor. The term is used most often in connection with atomic bombs; the tamper's inertia helps to delay the expansion of the fissionable material on explosion.

target

1. Material subjected to bombardment or irradiation by nuclear particles, electrons, or electromagnetic radiation, in order to induce nuclear reactions.
2. A nuclide which has been bombarded or irradiated by nuclear particles, electrons, or electromagnetic radiation. (Nuclear science) (1) A substance or object exposed to bombardment or irradiation. A **thin target** is one of thickness so small that there is negligible energy loss or absorption of the incident particles or photons traversing it. A **thick target** is one of such thickness that there is appreciable energy loss or absorption of the incident particles or photons traversing it. An **infinitely thick target** is one of such thickness that there is complete absorption of the incident particles or photons. (2) The initially stationary atom or nucleus in a nuclear reaction (*See reaction, nuclear*) (X-ray tube) Part of the anode upon which the electron stream impinges. In tubes designed for medical purposes, the target is usually of high atomic number and high melting point; in those designed for other purposes such as diffraction studies, metals of lower atomic number are frequently utilized.

target theory, hit theory (radiobiology)
Theory explaining some biologic effects of radiation on basis of ionization occurring in a very small sensitive region within the cell. One, two, or more hits, i.e., ionizing events within the *sensitive volume* may be necessary to bring about the effect.

tau meson
(See meson)

technetium (Tc)
An element, atomic number 43, first identified in 1937 by C. Perrier and E. Segrè as a product of deuteron and neutron bombardments of molybdenum, and later found also among the fission products of uranium from which the 2.1×10^5y Tc^{99} can be isolated in comparatively large quantities. No technetium has been found in nature, and no stable isotopes appear to exist; but a large number of radioactive isotopes are now known. The name of the element is derived from the Greek word *technetos*, meaning artificial. The

chemistry of technetium is similar to that of rhenium.

temperature coefficient
One of a group of coefficients relating changes in reactivity of a nuclear reactor to changes in temperature of its components; the derivative of reactivity with respect to temperature. If the effect of these coefficients is negative so that a change in power level (hence in temperature) produces an opposite change in reactivity, the reactor may hold a nearly steady power level with very little further regulation. (*Cf. self regulation*)

tensor force
(See nuclear forces)

ternary fission
(See fission, nuclear)

tertiary creep
(*See creep*)

texture
(See orientation)

thallium (Tl)
An element, atomic number 81, atomic weight 204.39. Several thallium isotopes are members of the uranium, actinium, thorium, and neptunium radioactive series.

theoretical stage (plate)
A hypothetical device for bringing two streams of material into such perfect contact that they leave in equilibrium with each other.

thermal analysis (metallurgy)
A method of determining the temperatures of phase transformations by measuring the discontinuities in the slopes of the temperature-time curves obtained upon heating or cooling.

thermal column
A column or large body of moderator, such as graphite, extending away from the active section of a nuclear reactor to provide near its other end, for experimental purposes, a flux of thermal neutrons of high cadmium ratio, i.e., containing few virgin and epithermal neutrons. (*See nuclear reactor*)

thermal cross section
The cross section as measured with thermal neutrons.

thermal cycle (reactor engineering)
A cycle of operation in which heat is transferred from one part of a system to another or converted to or from another form of energy (especially mechanical) by changes in the temperature of a medium, usually a fluid. A **compound cycle** is one employing more than one circuit, e.g., one or more heat-transfer circuits to remove heat from the reactor and a separate power circuit. Separate heat-transfer and power circuits are desirable to prevent the fluid circulating through the first, which will become radioactive, from contaminating the equipment of the power circuit; sometimes engineering considerations make two successive heat-transfer stages desirable. Compound cycle systems may be designated according to the number of circuits used, e.g., binary or ternary. These circuits may be designated **primary** or **secondary** according to their place in the sequence of heat transfers. The terms **core circuit** and **intermediate circuit** sometimes are applied to the two heat-transfer circuits of a ternary system, in which the first removes heat from the reactor core and the second transfers it to a power circuit.

thermal diffusion, soret effect (isotopes separation)
The phenomenon by which a temperature gradient in a mixture of two or

more fluids tends to establish a concentration gradient. In a binary isotopic mixture in which a steady state temperature gradient is established, and in which there is no convective flow, the equilibrium distribution is given by:

$$\left(\frac{N_1}{1-N_1}\right)T^{-\alpha_T} = \text{const.}$$

Here N_1 is the mole fraction of the component, and α_T is the thermal diffusion constant, related to the thermal diffusion coefficient D_T by

$$D_T = \alpha_T N_1 (1 - N_1) D_{12}$$

where D_{12} is the ordinary diffusion coefficient. For isotopic mixtures, α_T, unlike D_T, is substantially independent of concentration. It is also, within wide limits, independent of pressures, and has no strong dependence on temperature.

thermal diffusion method
A method for separating isotopes depending on the difference in rates of diffusion of gases or liquids of different molecular weights across a temperature gradient.

thermal inertia
Reciprocal of *thermal response.*

thermal instability (of a reactor)
A positive temperature coefficient, especially in a component of low heat capacity. A thermally unstable reactor tends to run away unless well controlled. (*See stability; temperature coefficient*)

thermal neutrons
Neutrons in thermal equilibrium with the substance in which they exist; most commonly, neutrons of kinetic energy about 0.025 ev, which is the mean kinetic energy of a molecule at 15 °C.

thermal reactor
(See nuclear reactor)

thermal response
Rate of temperature rise in a reactor operating at its rated power if no heat is withdrawn by cooling. The reciprocal of this rate is called thermal inertia.

thermal shield (reactor engineering)
A high density heat-conducting portion of a shield placed close to the reflector. Its purpose is to remove a major portion of the energy carried by the radiation emanating from the core to protect outer parts of the shield, usually concrete, from thermal damage. Its function is (a) to absorb thermal neutrons, which would heat the outer shield on being captured by its atoms, or (b) to absorb a large amount of the gamma, beta, and x-radiation, whose absorption in the outer shield would generate heat. For these purposes, a thermal shield is likely to be a very heavy metal wall, which will have considerable absorption for both gamma rays and slow neutrons and will have high thermal conductivity so that the heat generated within it can reach the surface for removal. A thermal shield is likely to require a special flow of coolant, which may or may not be the same used in the active section.

thermal siphon (isotopes separation)
A closed loop containing fluid. One vertical member of the loop is kept at a different temperature from that of another vertical member. In this way circulation is established without the use of a pump.

thermal utilization
The probability that a thermal neutron which is absorbed is absorbed usefully; usually used to describe the probability that a neutron is absorbed in a fissionable material.

thermonuclear reaction
(See reaction, thermonuclear)

thick target
(See target)

thimble ionization chamber
(Radiobiology) A small cylindrical or spherical ionization chamber, usually with walls of organic material. (Instrumentation) A thimble-shaped ionization chamber of small volume, (≤ 5 cm^3), usually of "air-wall" construction.

thin target
(See target)

"thin-window" counter tube, "thin-wall" counter tube
Counter tubes in which a portion of the enclosure is of low absorption to permit the entry of short-range radiation.

Thomson scattering
The scattering of electromagnetic radiation by electrons, interpreted classically as a process in which some of the energy of the primary radiation is reduced because the electrons radiate when accelerated in the transverse electric field of the radiation. The scattering cross section is given by

$$\sigma_T = \frac{8}{3}\pi\left(\frac{e^2}{m_e c^2}\right)^2 = 0.66 \text{ barn/elec-}$$

tron, and is called the **Thomson cross section,** or the **classical scattering cross section.** (*See scattering*)

Thoraeus filter
A primary filter of tin, with a secondary filter of copper to absorb the characteristic radiation of the tin, and a tertiary filter of aluminum to absorb the characteristic radiation of the copper. In the 200-400 kv region such a filter hardens the radiation more efficiently than the usual combination of copper and aluminum.

thorianite
A mineral consisting largely of thorium oxides with oxides of the cerium metals, uranium, etc.; important as an ore of thorium and uranium.

thorides
1. A name proposed for elements of the last row of the periodic system in oxidation state +4. The compounds of the elements beyond thorium in this state are generally isostructural with the corresponding ones of thorium.
2. A name proposed for the series of elements immediately following thorium (atomic number 90) based on the assumption that filling of the $5f$ electron shell begins with protactinium (atomic number 91). This name has not received as wide acceptance as has the name *actinides.*

thorite
A mineral consisting essentially of thorium silicate, $ThSiO_4$.

thorium (Th)
An element, atomic number 90, atomic weight 232.12. Important as a fertile material because Th^{232} may absorb neutrons and, decaying through the intermediate element protactinium, yield a fissionable isotope of uranium (U^{233}). Thorium itself undergoes fission to some extent with fast neutrons. Naturally occurring thorium consists, by weight, almost entirely of the 1.39×10^{10}y alpha-emitting Th^{232}. The 8.0×10^4y Th^{230} can be isolated from some uranium minerals. A number of other naturally occurring and artifically produced radioactive thorium isotopes are known, among them

the 23.5*m* Th^{233} which is produced by neutron capture from Th^{232}; it is an intermediate in the preparation of the slow-neutron-fissionable U^{233} which is formed from it by the decay chain

$$Th^{233} \xrightarrow[(23.5m)]{\beta^-} Pa^{233} \xrightarrow[(27.4d)]{\beta^-} U^{233}$$

thorium A (ThA)
The common name for 0.158*s* Po^{216}, a member of the *thorium series.*

thorium B (ThB)
The common name for 10.6*h* Pb^{212}, a member of the *thorium series.*

thorium C (ThC)
The common name for 60.5*m* Bi^{212}, a member of the *thorium series.*

thorium C′ (ThC′)
The common name for 3.04×10^{-7} *s* Po^{212}, a member of the *thorium series.*

thorium C″ (ThC″)
The common name for 3.1*m* Tl^{208}, a member of the *thorium series.*

thorium D (ThD)
The common name for Pb^{208}, the stable end product of the *thorium series.* Natural lead contains 52.38% of this isotope.

thorium X (ThX)
The common name for 3.64*d* Ra^{224}, a member of the *thorium series.*

thorium series
The series of nuclides resulting from the decays of Th^{232}. Mass numbers of all members are given by 4*n*, where *n* is an integer. The sequence is also known as the **4n series.** Many synthetic nuclides decay in collateral series into this sequence. The sequence of decay in the thorium series as it occurs in nature is as indicated in fig. 8. (*See radioactivity, natural*)

thoron (Tn)
The common name for 54.5*s* Em^{220}, a member of the *thorium series.* (*See emanation*)

threshold dose
(See dose, threshold)

threshold energy, threshold

1. The energy limit for an incident particle or photon below which a particular *endothermic* reaction will not occur. It is specified with reference to the laboratory system of coordinates. For a reaction between two nonrelativistic particles, the relation of the threshold energy to the *Q-value* is

   Threshold energy =

   $$-Q\frac{(\textit{mass of incident particle})}{(\textit{mass of target nucleus})} + 1.$$

2. The energy limit for an incident particle or photon below which a particular nuclear reaction cannot be observed; sometimes called the **practical threshold energy.** It is frequently determined by Coulomb barrier effects. *Exothermic* as well as *endothermic* reactions may have threshold energies.

thrombocyte
(See platelet)

time lag (counter)
The time between the occurrence of the primary ionizing event and the occurrence of the count.

tissue dose
(See dose, tissue)

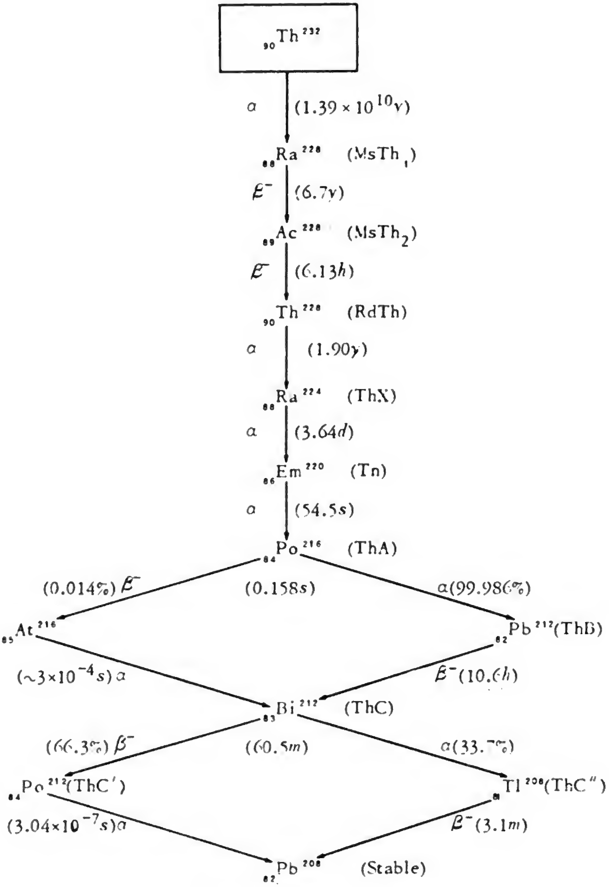

Fig. 8. The thorium series.

tissue equivalent ionization chamber
(See ionization chamber, tissue equivalent)

tissue equivalent material (radiobiology)
Material made up of the same elements in the same proportions as they occur in some particular biological tissue. Such material is important in the construction of ionization chambers for neutron measurement. In some cases the equivalence may be brought about sufficiently closely without exact duplication of the elemental composition of the tissue. (*See atomic number*)

tolerance dose
(See dose, tolerance)

total cross section
For a given medium, the sum of the cross sections for all mutually exclusive processes. (*See cross section* σ)

total ionization
(See ionization, total)

Townsend avalanche, Townsend ionization
(See avalanche)

trace
1. A minute quantity.
2. A small quantity detectable only by special techniques.
3. An adjective pertaining to such minute quantities.

trace chemistry
The chemical behavior of a substance present in a system in imponderable amount or in very minute concentration. Trace chemical behavior is observable with radioactive nuclides free or nearly free of non-radioactive isotopes, and may be markedly different from the behavior of the same material in ordinary amounts and concentrations. Knowledge of trace chemical behavior may therefore be of great importance in the handling of radioactive materials. Characteristic features of trace chemical behavior include the prominence of surface effects (*see adsorption*), incorporation of the trace material in bulk precipitates (*see carrier*), and dissociation (e.g., the stability of bromine atoms in aqueous solutions of trace bromine). (*See tracer chemistry; tracer, isotopic*)

trace concentration
A concentration of a substance below the usual limits of chemical detection. Commonly concentrations below about 10^{-9} molar are considered as trace concentrations. Radionuclides are often observable in trace concentration by means of their radioactivity.

tracer
A foreign substance mixed with or attached to a given substance to enable the distribution or location of the latter to be determined subsequently. A **physical tracer** is one that is attached by purely physical means to the object being traced. A **chemical tracer** is one that has chemical properties which are similar to those of the substance being traced and with which it is mixed homogeneously. A **radioactive tracer** is a physical or chemical tracer having radioactivity as its distinctive property. An **isotopic tracer** is a radionuclide or an *allobar* used as a chemical tracer for the element with which it is isotopic. (*See indicator; carrier; interchange*)

tracer, isotopic
1. The isotope or non-natural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological or

physical process. The observations may be made by measurement of radioactivity (in the case of radioactive tracer) or of isotopic abundance, e.g., by mass spectrographic or density measurement.

2. Material in which isotopic tracer has been incorporated. (*Cf. trace chemistry*)

tracer chemistry

1. The use of isotopic tracers in chemical studies.
2. Loosely used for *trace chemistry.*

tracer studies

A technique for studying the role of an element, a group of elements, or a compound in a biological, chemical or physical process. In this technique an isotopic tracer is employed to follow the course of the bulk material through the process. Either stable or radioactive isotopes can be used, in any desirable chemical form, but in case of radioactive tracers the amount must be so small that the radiation will not interfere with the natural course of the process under study.

track (nucleonics)

Visual manifestation of the path of an ionizing particle in a cloud chamber or nuclear emulsion.

transformation (metallurgy)

A change from one phase to another, or a change in the number of phases present in a system. The **transformation temperature** is the temperature at which the change occurs when it takes place isothermally. The **transformation range** is the temperature interval over which phase changes take place when the composition of the product phase or phases varies from the beginning of the transformation to its end. (Often called **transition.**)

transformation chain, family, or **series**

Synonyms for *radioactive series.*

transformation constant

A synonym for *disintegration constant.*

transient radioactive equilibrium

(See radioactive equilibrium)

transition

(See transformation)

transition, isomeric

(See isomeric transition)

transition effect

A change in the intensity of the secondary radiation associated with a beam of a primary radiation as the latter passes from a vacuum into a material medium, or from one medium into another. (*See radiation, secondary*)

transition multipole moments

(See multipole moments)

transition probability

The probability per unit time, symbol w_{if}, that a system in state i will undergo a transition to state f. The quantity

$$w_i = \left[\begin{array}{l}\Sigma\, w_{if}\\ \text{over}\\ \text{all } f\end{array}\right]$$

is the **total transition probability** for state i. The probability that the system is still in state i at the end of time t is then $e^{-w_i t}$. For radioactive transitions, the symbol λ is used instead of w_i, and the total transition probability is then called the *disintegration constant.*

translocation

(See chromosome translocation)

transmission coefficient
A synonym for *penetration probability.*

transmission curve
(See absorption curve)

transmission experiment
An experiment in which a sample of material is placed between a source of radiation and a detector that registers the intensity of the transmitted radiation as a function of, say, the intensity of the incident radiation or the thickness of the absorbing material. Transmission experiments are commonly used in the measurement of the total cross sections for neutrons.

transmutation (nucleonics)
1. Any process in which a nuclide is transformed into a different nuclide.
2. More specifically, the transformation of a nuclide into a nuclide of a different element by a nuclear reaction.

transparent
Permitting the passage of radiation or particles (opposite of *opaque*). The term usually is qualified as to the radiation involved—e.g., bismuth is highly transparent to neutrons but opaque to gamma rays. The term is likely to be relative with respect to thickness, for, especially with gamma rays, which have no fixed range and are absorbed approximately exponentially with distance, a thin layer of a given material may be transparent to these rays but a thick one substantially opaque.

transport (isotopes separation)
The total rate at which desired isotopes are carried toward the production end of the plant through any section.

transport cross section
The reciprocal of the *transport mean free path.*

transport mean free path
1. Where *Fick's law* is applicable, three times the diffusion coefficient of neutron flux.
2. A modified mean free path used to correct for the persistence of velocities and anisotropy of scattering.

transport theory
A theory based on an approximation to the *Boltzmann equation* for such conditions that *Fick's law* is not applicable.

transuranium elements
Elements of atomic number greater than 92. Those known at present are neptunium, plutonium, americium, curium, berkelium, and californium.

trauma (biology)
Injury.

tritium ($_1H^3$ or T)
The hydrogen isotope of mass number 3. The mass is 3.01695 amu. It decays with a half-life of 12.5y, emitting a β-ray of maximum energy 0.0189 Mev. The symbol T is often used to designate tritium in compounds (or for compounds with appreciable tritium content for isotopic tracer), as HTO for molecules of that composition or for water labeled with tritium. Official chemical nomenclature uses the designation *t* with a number which designates the carbon atom to which the tritium is bound, e.g., 2-*t* propane designates CH_3CHTCH_3.

triton, t
The nucleus of tritium, the hydrogen isotope of mass number 3, in its use as a nuclear projectile or as a prod-

uct of a nuclear reaction, as ${}_{16}S^{32}(t,n){}_{17}Cl^{34}$ and ${}_{17}Cl^{37}(n,t){}_{16}S^{35}$.

trochoidal mass analyzer
A mass spectrometer wherein the ion beams traverse trochoidal paths within electric and magnetic fields mutually perpendicular.

trochotron
A multi-electrode tube used for scaling which operates by utilizing an electron beam in a magnetic field to change elements in sequence.

tube conveyor
A passage in a nuclear reactor for a rabbit or shuttle. (*See rabbit*)

tumor (biology)
A swelling. The term is usually synonymous with *neoplasm* but may be more vague.

tungsten
(See wolfram)

tungsten carbide
Compound of wolfram (tungsten) and carbon. The composition varies between WC (melting point 2777°C) and W_2C (2857°C). It has been suggested for use in high-temperature reactors.

turbulent flow
Fluid flow in which the local velocity of the fluid medium varies erratically with time in both direction and magnitude.

twinning (metallurgy)
A process in which a region in a crystal assumes an orientation which is symmetrically related to the basic orientation of the crystal. Usually, layers of atoms within this region are translated with respect to a basic plane, the **twinning plane.** Each atomic plane is displaced by a distance which is proportional to its distance from the twinning plane. Bands of metal (**twin bands**) thus assume a lattice structure which is the mirror image of the unchanged portion of the lattice.

two-group model
(See multi-group model)

U

uncertainty principle
A synonym for *indeterminancy principle.*

unloading machine
A machine for removing fuel from a nuclear reactor. (*See loading machine*)

unstable (adj.)
Capable of undergoing spontaneous change. Of a *nuclide, radioactive;* of a state of a system, *excited.* (*See metastable*)

uranides

1. A name proposed for the elements beyond protactinium in the periodic system in recognition of the occurrence of a transition group in which uranium is a prominent member, and the first of a sequence of elements (including neptunium, plutonium, and americium) with the same pattern of oxidation states. *(See actinides)*
2. A name proposed for elements of the last row of the periodic system in oxidation state +6. The compounds of the elements beyond uranium in this state are generally isostructural with the corresponding ones of uranium.

uraninite
Pitchblende.

uranium (U)
An element, atomic number 92, atomic weight 238.07. Naturally occurring uranium is a mixture consisting of 99.28% U^{238}, 0.71% U^{235}, and 0.00580% U^{234} (formed by decay of U^{238}). All three isotopes are alpha-active, with half-lives of 4.498×10^9y, 8.8×10^8y, and 2.67×10^5y respectively. The nucleus of U^{235} is capable of absorbing a neutron of thermal energy and thereupon undergoing fission into two fragments, which fly apart with great energy. The fragments are highly radioactive. Some neutrons are released almost immediately in each fission (the *prompt neutrons*). A small fraction (*delayed neutrons*) is released later in the radioactive decay of some of the fission products. The fact that fission is induced by one neutron but releases more than one makes possible a *chain reaction.* The fact that some are delayed simplifies control problems. The proportion of U^{235} in natural uranium may be increased artificially by any of several processes, of which gaseous diffusion is the most important. (*See isotope separation*) The resulting material is called enriched uranium. U^{238}, which undergoes fission with fast neutrons, may absorb slower neutrons and, decaying through the intermediate element neptunium, yield plutonium, which is fissionable and can be separated from uranium by chemical methods. **Alpha uranium** is that allotropic modification of uranium metal which is stable below approximately 660 °C. It has an orthorhombic crystal structure. **Beta uranium** is that allotropic modification of uranium which is stable between approximately 660 °C and 770 °C. It has a tetragonal crystal

structure. **Gamma uranium** is that allotropic modification of uranium which is stable above approximately 770 °C. It has a body-centered cubic structure. Uranium is of great importance as the ultimate source of the two slow-neutron fissionable nuclides U^{235} and Pu^{239}. (*See also plutonium*)

uranium-233 (U^{233})
A synthetic isotope of uranium discovered in 1942 by Seaborg, Gofman and Stoughton. It is an alpha emitter with a half-life of $1.62 \times 10^5 y$ and is fissionable with slow neutrons. It can be produced from Th^{232} by slow neutron irradiation via the following series of reactions:

$$Th^{232}(n, \gamma)$$

$$Th^{233} \xrightarrow[(23.5m)]{\beta^-} Pa^{233} \xrightarrow[(27.4d)]{\beta^-} U^{233}$$

uranium-235 (U^{235})
The $8.8 \times 10^8 y$ alpha emitting uranium isotope, fissionable with slow neutrons, occurring in natural uranium to the extent of 0.71%.

uranium-I (U_I)
The common name for $4.498 \times 10^9 y$ alpha emitting U^{238}, the natural parent of the *uranium series.* Its concentration in natural uranium is 99.28%.

uranium-II (U_{II})
The common name for $2.67 \times 10^5 y$ U^{234}, a member of the *uranium series.* Its concentration in natural uranium (formed by decay of U^{238}) is 0.00580%.

uranium X_I (UX_I)
The common name for 24.1*d* Th^{234}, a member of the *uranium series.*

uranium X_2 (UX_2)
The common name for 1.14*m* Pa^{234}, a member of the *uranium series.* Sometimes called **brevium.**

uranium Y (UY)
The common name for 25.65*b* Th^{231}, a member of the *actinium series.*

uranium Z (UZ)
The common name for 6.7*b* Pa^{234}, isomeric with UX_2, a member of the uranium decay series.

uranium reactor
A nuclear reactor in which the principal fuel is uranium. The uranium may be **natural,** i.e., with the naturally occurring ratio of one atom of U^{235} to about 139 of U^{238}, or **enriched** i.e., having a higher proportion of fissile uranium atoms (U^{233} or U^{235}).

uranium series
The series of nuclides resulting from the decay of U^{238}. Mass numbers of all members are given by $4n + 2$, where n is an integer. The sequence is also known as the **uranium-radium series** and the **$4n + 2$ series.** Many synthetic nuclides decay in collateral series into this sequence. The sequence of decay in the uranium series as it occurs in nature is indicated in fig. 9. (*See radioactivity, natural; radium*)

useful beam (radiology)
That part of the primary radiation which passes through the aperture, cone, or other collimator.

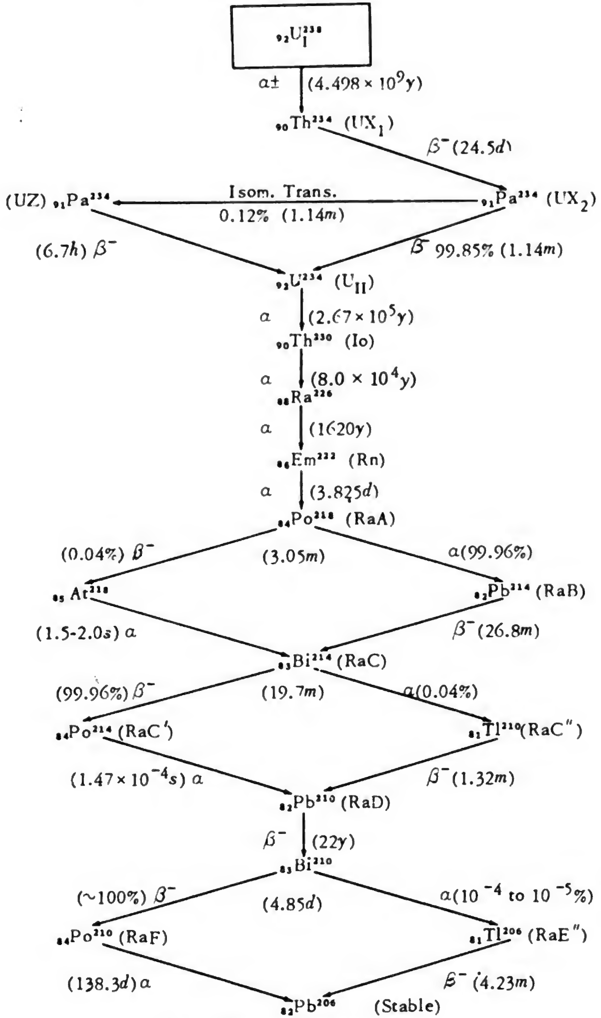

Fig. 9 The uranium series.

V

vacancy (metallurgy)
An unoccupied atomic site in a crystal structure.

value (isotopes separation)
A measure of the difficulty of preparing a quantity of an isotope mixture. It is proportional to the amount of the mixture, and is also a function of the composition of the mixture. The change in the value created by a cascade is directly proportional to the number of separating elements it contains. For a binary mixture, the value of Q moles of mixture, taking the equimolar mixture as the reference state, is given by

$$Q(2N-1)\log_e R$$

when $N =$ mole fraction of either component
$R = N/(1-N) =$ molecular abundance ratio.
When referred to an arbitrary mole fraction N_o as the reference state the value of Q moles of mixture is given by

$$V = \left\{ (2N-1)\log_e \frac{N(1-N_o)}{N_o(1-N)} + \frac{(N-N_o)(1-2N_o)}{N_o(1-N_o)} \right\} Q$$

The total value created by a separating plant is the difference between the total value of all outgoing materials and the total value of all ingoing materials. This resultant is independent of N_o.

Van de Graaff generator
An electrostatic generator which employs a system of conveyor belt and spray points to charge an insulated electrode to a high potential.

vibrating condenser, vibrating reed dynamic condenser
A condenser whose capacitance is varied in a cyclic fashion so that an alternating emf is developed proportional to the charge on the insulated electrode. This device forms the basis for a type of electrometer. (*See vibrating reed electrometer*)

vibrating contactor
A device which periodically makes and breaks contact in a cyclic fashion, used for converting d-c signals to a-c signals. It is also called a vibrator or chopper.

vibrating reed electrometer
An instrument using a vibrating condenser to measure a small charge. This term is often applied to denote the combination of an ionization chamber and a vibrating reed electrometer.

Vickers hardness
(See hardness)

virgin neutron flux
A flux of neutrons that have suffered no collisions and therefore have lost none of the energy with which they were born.

virgin neutrons
Neutrons from any source, before they make a collision.

virtual level, virtual state

1. A quasi-stationary energy level or state of a compound *nucleus*, characterized by a lifetime long compared with the transit times of the nucleons across nuclear dimensions at energies corresponding to the excitation in question; therefore, very often a *resonance level*.
2. A term that has frequently been used to refer to the so-called unbound singlet state of the deuteron. However, such a usage gives this "state" undue importance, for it does not actually exist; its invention arose from the merely formal possibility of calculating a fictitious negative binding energy of the singlet neutron-proton system that would give the same scattering length as is observed in neutron-proton scattering.

virtual quantum
In second and higher order perturbation theory, a *matrix element* connecting an initial state with a final state involves intermediate states in which energy is not conserved. A *quantum* or *photon* in such an intermediate state is termed a virtual quantum. Thus the self-energy of an electron (due to the electromagnetic field) is pictured as arising from the continual emission and reabsorption by the electron of virtual quanta. Similarly the Coulomb energy between two electrons may be pictured as arising from the emission of virtual quanta by one of the electrons and their absorption by the other.

viscous flow
(See streamline flow)

volume dose
(See dose, integral)

volume ionization
Average ionization density in a given volume irrespective of the specific ionization of the ionizing particles.

W

water
Oxide of hydrogen, H_2O, important in nuclear reactors both as a coolant and as a moderator. The hydrogen in ordinary or **light water** is ordinary or light hydrogen (atomic weight 1). In **heavy water** it is heavy hydrogen or deuterium (atomic weight 2). The heavy hydrogen atoms have less slowing-down power than the light but lower neutron capture cross section. Heavy hydrogen constitutes a small portion of natural hydrogen, from which it is extracted by an isotope separation process to produce *heavy water.*

water monitor
Any device for detecting and measuring waterborne radioactivity for warning and control purposes.

wave function, Schroedinger
A function $x\ (\tau)$ of the coordinates that determines the state of a system and satisfies the Schroedinger wave equation, $H\,x = i\,h\,(dx/dt)$, where H is the Hamiltonian operator and $i = \sqrt{-1}$. For a particle or a photon, the square of the wave function is proportional to the probability that the particle will be at a particular point at a particular time.

weighting function
A measure of the relative effect on reactivity of localized changes in nuclear properties as a function of position and property change.

welding
A process of joining metals by the application of heat or pressure or both. In **fusion welding** joining is accomplished by localized melting of the parent metal, thus distinguishing this process from soldering or brazing. **Pressure welding** involves joining the metals by application of heat and pressure or by pressure alone.

Arc welding is a fusion welding process in which an electric arc is struck between a metal or carbon electrode and the metal being welded; between two separate electrodes, as in atomic hydrogen welding; or between the two pieces being welded, as in flash welding. In **shielded-arc welding,** the metal electrode is coated with a flux which may produce an envelope of protective gases and a protective slag covering on the weld. **Inert-gas-shielded-arc welding** employs a blanket of inert gas such as argon or helium about an arc drawn between a tungsten electrode and the metal work. It is used for the welding of easily oxidized metals or where flux is objectionable.

Gas welding is a fusion process in which heating is accomplished by a torch ordinarily fed with a fuel containing oxygen and a hydrogenous or hydrocarbon gas. Usually, oxygen-hydrogen or oxygen-acetylene mixtures are employed.

Resistance welding is a process in which the metals to be joined are heated to a plastic or fused condition by a localized electric current, and pressure is applied to secure a union. In **spot welding,** the fusion is limited to a small area. In **seam welding,** the lapped metal sheets are passed between roller contacts and a series of overlapping spot welds are made by intermittent application of current. In **percussion welding,** a sudden discharge of electric current at the junction produces an arc which is extinguished by a percussive blow.

Widmanstätten structure
A structure in which a geometrical metallographic pattern is produced by the generation of a new phase within the body of the parent phase. The shape of the particles of the new phase and their crystallographic orientations are both related to the orientation of the parent crystal.

Wigner effect
The *discomposition* effect.

Wilson chamber
(See cloud chamber)

window (reactor engineering)

1. An aperture for the passage of particles or radiation, usually closed with a filter for restricting the kind transmitted, or the filter itself. A typical example is a lead or bismuth window used to admit neutrons to a *biological hole* but exclude gamma rays.
2. An energy range of relatively high transparency in the total neutron cross section of a material. Such windows arise from interference between potential and resonance scattering in elements of intermediate atomic weight and can be of importance in neutron shielding.

wolfram (W)
(Formerly **tungsten**) A metallic element, number 74 in the atomic series, with melting point 3370 °C. It has been suggested for use in high-temperature reactors, especially as a shielding material.

X

x-ray diffraction instrument
(See diffraction instrument)

x-ray spectrum
(See spectrum)

x-rays
Electromagnetic radiation of wavelengths less than about 100 Å, produced: (i) when electrons striking a target lose kinetic energy in passing through the strong electric fields surrounding the target nuclei, thus giving rise to *bremsstrahlung* and resulting in a continuous x-ray *spectrum*; (ii) by the transitions of atoms from *K*, *L*, ...energy states to lower energy states, thus giving rise to **characteristic x-rays.** The term x-rays is not used to refer to the characteristic radiation from an element of atomic number *Z* less than 10, since the wavelengths of such radiation exceed those in the x-ray range. X-rays are usually produced by bombarding a metallic target with fast ELECTRONS. ~~neutrons~~ in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as *gamma rays*, and to those originating in the extranuclear part of the atom as x-rays. These rays were called x-rays by their discoverer, Roentgen. Many medical radiologists prefer to call them by his name; non-medical usage is generally x-rays.

x-unit, Xu
A unit used in expressing the wavelengths of x-rays or gamma rays. It is about 10^{-11} cm or 10^{-3} angstrom. $1 \text{ Xu} = 1.00202 \pm 0.00003 \times 10^{-3}$ angstroms.

Y

Y-12
The code name for the electromagnetic separation plant at Oak Ridge, Tennessee.

yield, G
In radiation chemistry the number of molecules produced or converted per 100 ev of energy absorbed.

ylem
The primordial substance from which the chemical elements may have been derived. (*See nucleogenesis*)

Young's modulus
(*See modulus of elasticity*)

Yukawa potential
A potential function of the form $V = \text{const.}\, \frac{e^{-kr}}{r}$. It is used to describe the meson field about a nucleon. The Yukawa potential is employed rather frequently as one shape of nuclear potential well that can be used in attempts to fit theory with experimental results, for example, in high-energy scattering. It is characterized by (i) infinite strength at $r = 0$, (ii) an exponential tail extending with appreciable strength to larger r rather than a Coulomb potential. (*See potential, nuclear; nuclear forces*)

Z

Z
A symbol for *atomic number*.

zero-power reactor
An experimental nuclear reactor operated at low neutron flux and at a power level so low that not only is no forced cooling required but also fission product activity in the fuel is sufficiently low to allow the fuel to be handled after use without serious hazard.

zirconium (Zr)
A metallic element, number 40 in the atomic series, important as a possible structural material for nuclear reactors because it has good mechanical properties at high temperature and, when pure, has a low absorption cross section for thermal neutrons.

zygote (biology)
The cell resulting from the union of two gametes; in animals, the fertilized diploid egg.

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